FOOD INGESTION AND ENERGY TRANSFORMATIONS

WITH SPECIAL REFERENCE TO

THE STIMULATING EFFECT OF NUTRIENTS

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FOOD INGESTION AND ENERGY TRANSFORMATIONS

WITH SPECIAL REFERENCE TO

THE STIMULATING EFFECT OF NUTRIENTS

By Francis G. Benedict and Thorne M. Carpenter

FOOD INGESTION AND ENERGY TRANSFORMATIONS WITH SPECIAL REFERENCE TO THE STIMULATING EFFECT OF NUTRIENTS.

INTRODUCTION.

During the period of gestation the fetus is supplied with nourishment from the mother through the placenta and no muscular movement or exertion of any kind is required to secure food. After birth much of the muscular activity of infants is a direct or indirect effort to secure nourishment. This includes not only the act of suckling but also the muscular activity and crying due to hunger. Thus the apparently anomalous condition exists of an expenditure of a considerable amount of energy for the purpose of obtaining energy for vital processes.

With animals of prey there is usually a period of intense muscular activity prior to feeding. The chase, the attack, the act of killing and tearing apart of the prey, all make demands upon the energy supply of the animal. After feeding, there is usually a relatively long period of muscular repose, although, as will be seen later, immediately after eating there is invariably an increase in the internal cellular activity incident to the process of digestion.

Even with non-predatory animals and birds a considerable amount of energy is necessary to secure food. The trails to the feeding-grounds, "salt-licks," and watering-places often lead over considerable distances. Birds fly enormous distances to special feeding-grounds, while with birds of prey the chase and attack are comparable to those of animals of prey.

An exception to this general activity in securing food is the serpent, which, instead of having to chase its prey, lies in wait for it. When the victim is captured, the serpent kills it either by poison, which of itself requires no muscular activity other than the act of striking, or by constriction, which usually continues but a short time. Probably no living organism secures its food with so economical a consumption of energy as the serpent does, not only because of its extraordinarily low metabolism, which permits it to live for a long time without food, but also because of the minimum amount of muscular activity expended in obtaining the food. With the human infant the muscular activity incidental to securing food plays a very important rôle. To what extent irritation and discomfort, accompanied by vigorous muscular exercise and crying, may be directly charged to a desire for nourishment is problematical, but in any event it is certain that a large part of the physical activity of an infant is due to an effort to secure food.

In human civilization it is rarely that an individual must pursue, attack, gather, and prepare his food prior to eating, as the food materials

are gathered by harvesters, hunters, or fishermen, brought to the dwelling by transportation agencies, prepared by some member of the household, and finally placed upon the table ready for consumption. With humans the exertion necessary to secure food is no longer individual, but represents the serious occupation of a large number of persons devoted to this service only. But even after the food has been prepared and placed before the individual, there are certain muscular processes necessary to prepare it for digestion; these are admirably classified by Armsby in the following paragraph:

"In the process of digestion we are probably safe in assuming that the muscular work of prehension, mastication, deglutition, rumination, peristalsis, etc., constitutes an important source of heat production."[1]

Entirely aside from the external muscular activity incident to the procuring and preparing of food and its introduction into the mouth, we have internal processes other than those of mastication, primarily the movements of the stomach and intestinal tract, which may be grouped under the general term of peristalsis. These movements, certainly in ruminants, are very considerable in amount. While with humans rumination does not occur, yet the admirable X-ray observations of Cannon[2] have demonstrated that with men peristalsis is continuous during digestion. How much the movements of peristalsis and segmentation contribute to or make demands upon the energy of the body is a problem still to be considered. The possibility of there being extensive demands for these processes in man has been carefully considered by Zuntz and his co-workers. These investigators have been influenced in large part by their observations on ruminants and herbivorous animals in general, such animals having a large amount of residue or ballast in the gastro-intestinal tract that must be worked over by the peristaltic movements.

Finally, a considerable demand is made upon the energy of the body for heat to warm the ingesta. Water and many other fluids are commonly taken by man at a temperature considerably lower than the temperature of the body; these must be warmed to body-temperature. Again, certain liquids are taken somewhat above the temperature of the body and therefore may contribute, in part at least, to the heat elimination. The amount of cold ingesta required to be warmed by body heat is invariably much greater than the amount of warm food taken, so that in many instances we have carefully to consider this expenditure of heat. In fact, this has been pointed out as an important path for the output of heat in diabetics with an enormous excretion of urine. If 3 liters of water are taken and excreted as urine in the course of the day, it will be seen that this water may be warmed from

[1]Armsby, The principles of animal nutrition, 2d ed., 1906, p. 374.
[2]Cannon, The mechanical factors of digestion, 1911.

an average of 10° C. to the temperature of the body, or 37° C., with an expenditure of 81 calories.[1]

The feeling of warmth following the ingestion of food, familiar to all, is not without significance as being a crude index of a scientific fact which has been well established since the days of Lavoisier and Jurine, *i. e.*, that after food ingestion there is an increase in the metabolism or heat output. At present the main subjects for discussion with physiologists are not as to there being an increase in the heat output, but first, as to its quantitative relations to the ingesta; second, as to the cause of the increase in the heat output.

After an historical examination of the evidence with human subjects which has thus far been accumulated to show that there is an increased heat production following food, the results of an extensive series of observations made under the auspices of the Carnegie Institution of Washington, first in the Department of Chemistry of Wesleyan University, Middletown, Connecticut, and later in the Nutrition Laboratory in Boston, will be presented. These observations, covering a period of 10 years, were made with a variety of methods and somewhat changing technique, so that they are not strictly comparable in all instances. The evidence is, however, so extensive as to throw general light upon the metabolism following ingestion of food and justifies a consideration of the quantitative relations between the energy intake and character of the ingesta and the quantitative increase in the metabolism of man following the ingestion of the various diets.

[1]Benedict and Joslin, Carnegie Inst. Wash. Pub. No. 136, 1910, p. 230.

PREVIOUS INVESTIGATIONS ON METABOLISM AFTER FOOD.

Lavoisier and Séguin, 1789.—The fact that the ingestion of food causes an increase in the metabolism in the body was first made known through the classical researches of Lavoisier and Séguin.[1] As with many phases of physiological chemistry, our first information as to quantitative values for these important body processes is obtained from the remarkable series of experiments carried out by Lavoisier. Judging from incomplete statements appearing intermittently in the writings of Lavoisier and of Séguin, together with the drawings attributed to Madame Lavoisier, the expired air was collected by means of an air-tight mask attached to the subject's face. It is of interest to note that this method is now the basis of practically all of the modern mine-rescue apparatus and "gas-masks", and is also finding extensive use in clinical laboratories.

The statement is made by Lavoisier that a man fasting, or at least with an empty stomach and quiet, consumes in one hour 1,210 cubic pouces of oxygen. This corresponds, according to the table of reductions of Gavarret,[2] to 24.002 liters. Lavoisier also states that during digestion the oxygen consumption increases to 1,800 or 1,900 cubic pouces, the latter value corresponding to 37.689 liters. Thus we note an increment of approximately 700 cubic pouces due to taking food or, in other words, somewhat over 50 per cent. The kind of food and the amount eaten were not given. Lavoisier recognized the fact that individuality may play a rôle here; we cite his criticism:

"Nous ne parlons en ce moment que de rapports. On conçoit, en effet, que la consommation absolue doit varier considérablement dans différents individus, suivant leur âge, leur état de vigueur et de santé, suivant qu'ils ont plus ou moins contracté l'habitude des travaux pénibles; mais il n'est pas moins vrai qu'il existe pour chaque personne une loi qui ne se dément pas, lorsque les expériences sont faites dans les mêmes circonstances et à des intervalles de temps peu éloignés."[3]

In studying the literature 130 years after the appearance of Lavoisier's first paper, it is surprising to note his clear conceptions of the problems involved both in the muscular work of man and in digestion. While an increment in metabolism amounting approximately to over 50 per cent is somewhat higher than that commonly observed and somewhat higher, in all probability, than modern methods would show for the diet of the subject, nevertheless it is by no means an impossibility. We have thus this earliest recorded estimate of the increased energy required to digest a meal.

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[1]Séguin and Lavoisier, Mémoires de l'Acad. des Sciences, 1789, p. 185; also Oeuvres de Lavoisier, 1862, 2, p. 688.
[2]Gavarret, Physique médicale. De la chaleur produite par les êtres vivants. 1855, p. 330.
[3]Séguin and Lavoisier, Oeuvres de Lavoisier, 1862, 2, p. 696.

Jurine, 1789.—Almost simultaneously with Lavoisier's paper we have an interesting communication from Jurine of Geneva. In his researches Jurine employed a Fontana eudiometer, then much used in Europe as the earliest method for analyzing gases, particularly atmospheric air. With this apparatus he studied the influence upon the expired air of various physiological processes, among others those of the ingestion of food.[1] The experiments were confined exclusively to determinations of the differences in composition of the expired air. The subject evidently breathed through a glass tube flattened to fit the shape of the mouth, and the expired air was collected at times over water and at times over mercury in a bell-jar. A stopcock was turned at the beginning and end of each expiration. Among other experiments, Jurine made three on the influence of food upon the respiratory exchange as shown by the changes in the composition of the air. Both a fasting experiment and a food experiment were made with each of three subjects, a young girl 10 years old, a man 36 years old, and a woman 62 years old. The food experiments were to determine if the increased blood circulation, depending on or incident to digestion, would increase the oxygen consumption. In the air collected over water no change was found in the oxygen content, while in the air collected over mercury a very sensible increase was found in the proportion of carbon dioxide present. The total amount of carbon dioxide produced in 24 hours was computed by Jurine from the average number of respirations and from the volume expired per respiration. We find no evidence, however, that he calculated the total increase in the carbon-dioxide production due to digestion.

This method of studying the expired air was followed for a number of years by other scientists, little emphasis being placed upon the total quantitative amount of carbon dioxide expired in a given time, but chiefly upon the alteration in the carbon-dioxide content of the expired air. We know now that this change in composition has but little significance unless accompanied by some knowledge of the total ventilation of the lungs, a factor that was entirely overlooked, or at least undetermined, in many of the early researches.

Prout, 1813.—One of the most extended observations upon the influence of food on the carbon-dioxide percentage of the expired air is that recorded by Prout.[2] The subject, Prout himself, expired into a bladder, regulating the number of expirations to six. A sample of air was then taken in a tube and the carbon dioxide was determined by absorption with strong caustic potash. Prout remarks that as his main object was to discover general laws he did not pay so much attention to the question of the influence of food, although during the three weeks of experimentation he ate only the simplest food and with

[1] Jurine, Histoire et Mém. Soc. Méd., 1789, **10**, p. 19.
[2] Prout, Annals of Philosophy, 1813, 2d ed., **2**, p. 328.

as much regularity as possible. The effects from the food, therefore, were not remarkable. Apparently the food taken simply kept the carbon-dioxide production up to the standard and occasionally increased it somewhat, certainly never depressed it. Prout found that fermented liquor, which was occasionally taken, always depressed the carbon-dioxide production. Tea had a like depressing effect, for after 3 or 4 ounces of strong, cold tea he found a considerable diminution in the carbon-dioxide produced. As Prout was much surprised to note the depressing effect of alcohol and all liquors containing it, he made a number of observations on alcoholic liquors, which invariably gave the same result, *i. e.*, a depression of the carbon-dioxide excretion. In this consideration of his results, it is important to bear in mind the fact that his observations were solely on the percentage of carbon dioxide in the air. Little evidence is given in this paper to lead one to think that he had any conception of the total amount of the carbon-dioxide excretion. Scharling,[1] in citing Prout's experiments, concludes from the figures given for pulse rate that there really was a greater carbon-dioxide production after the ingestion of food than Prout noted.

Fyfe, 1814.—At about the same time as Prout's experiments, a number of observations were made by Andrea Fyfe,[2] of Edinburgh, which form the basis of a communication made by Prout in 1814.[3] Like Prout, Fyfe dealt exclusively with the percentage of carbon dioxide in the expired air. The expired air was collected in a bell-jar holding approximately 2.5 liters; the proportions of carbon dioxide and oxygen were then determined by means of a Hope eudiometer with the use of lime-water and sulphuret of lime. In an extensive series of experiments in which vegetable diets were given, Fyfe reports that the percentage of carbon dioxide fell from 8.5 per cent before the food experiment to about 4.5 per cent on the seventh and eighth days of the test. The experiments with animal diet lasted 8 days; on the fourth day the carbon dioxide was 7 per cent and on the seventh and eighth days 5 per cent. A repetition of the experiment gave values for the carbon-dioxide content on the third, fourth, fifth, sixth, and seventh days of 6 to 7, 7, 9, 5, and 8 per cent, respectively. When wine was taken, the carbon dioxide in the expired air was reduced in one experiment to between 2 and 3 per cent, and in another to 5.75 per cent.

Coathupe, 1839.—Twenty-five years after the experiments of Fyfe, Coathupe[4] made a series of observations on the products of respiration at different periods of the day, employing much the same apparatus

[1]Scharling, Ann. d. Chem. u. Pharm., 1843, **45**, p. 214. He speaks of Prout's results as being published in the Journ. f. Chem. u. Physik von Schweigger, 1815, **15**, p. 65.
[2]Fyfe, Dissertatio Chemico-Physiologica Inauguralis de Copia Acidi Carbonici e Pulmonibus inter respirandum evoluti, 1814.
[3]Prout, Annals of Philosophy, 1814, **4**, p. 331.
[4]Coathupe, Phil. Mag., 1839, 3d ser., **14**, p. 401.

as that used by Fyfe and Prout. Emphasis was laid solely upon the percentage of carbon dioxide in the expired air. The subject expired into a rubber bag having a capacity of 1,000 cubic inches; samples of air were then taken from this bag, the carbon dioxide being absorbed with lime-water. Experiments were made both before and after food. Coathupe concluded that the carbon dioxide produced in respiration is less during the period of active digestion, that it increases with increased abstinence from food, and that it varies with the same individual at similar periods of different days; excitement of any kind causes a decrease.

It is obvious that the researches of Jurine, Prout, Fyfe, and Coathupe, dealing as they do only with the percentage of carbon dioxide in the expired air, contribute but little of value to our knowledge of the actual changes in the total metabolism incidental to the ingestion of food. Until 1843, therefore, the only quantitative data on this subject to be found in the literature are those obtained in the research of Lavoisier and Séguin, in which it was noted that approximately a 50 per cent increase in the oxygen consumption followed the ingestion of food.

Scharling, 1843.—A considerable period of time intervenes between the early experiments of Lavoisier and the next stage of definite evidence. For the purpose of making direct determinations of the carbon dioxide produced by man, Scharling[1] constructed a large wooden box having a capacity of approximately 1 cubic meter and ventilated by a pump. The expired air was passed over a chain of glass vessels containing sulphuric acid, caustic potash, sulphuric acid, and lime-water respectively. The carbon-dioxide content of the air in the chamber was determined at the beginning and the end of the experiment. The periods were usually 1 hour long, although sometimes varying from 90 to 30 minutes; not more than one or two observations were made in 24 hours. The subjects, six in number, were allowed to read, talk, sew, write, etc., so complete muscular repose was not observed. The results given for each subject are the carbon-dioxide production in grams for the individual periods and per 24 hours, the pulse rate before and after meals, the ratio between day and night for the carbon-dioxide production, and the ratio between body mass and the carbon-dioxide production. Although the experimental technique has been criticized by Zuntz,[2] who has shown that undoubtedly carbon dioxide escaped absorption, nevertheless the general conclusions obtained by Scharling are not without interest, for he concludes that, other things being equal, man expires more carbon dioxide after he has eaten than when he is without food, and more when he is awake than when he is asleep. He finds that the maximum carbon-dioxide output occurs

[1]Scharling, Ann. d. Chem. u. Pharm., 1843, **45**, p. 214; reprinted in detail in Ann. d. Chim. et d. Phys., 1843, sér. 3, **8**, p. 478.
[2]Zuntz, Hermann's Handb. d. Physiol., 1882, **4**, (2), p. 123.

after the main meal of the day, independent of the hour at which it is taken. Scharling did not overlook the importance of noting the pulse rate, both in the fasting experiments and in those preceding and following the ingestion of food. Although his results may now have but little quantitative value, it is of importance to note that Scharling was the first to employ successfully the chamber principle of studying the respiratory exchange.

Vierordt, 1845.—The next two contributions to the experimental research on the respiratory exchange as affected by the ingestion of food unfortunately deal with a very imperfect method for both sampling and analyzing the expired air. Vierordt,[1] in making a very large number of observations on himself, employed a mouthpiece consisting of a short tube over which the lips closed. The nostrils were not closed during the experiment, as Vierordt thought it was impossible to breathe simultaneously through nose and mouth during quiet, normal respiration. The expired air was collected in a glass vessel containing 9,200 c.c., which was filled with a solution of common salt. About 1½ minutes were required to fill this vessel completely with expired air. Vierordt based his carbon-dioxide measurements on 1-minute periods, making two experiments in an hour. A mixed diet was taken in the food experiments. Of special interest in this connection are the comparisons made by Vierordt between the food experiments and the fasting experiments. On two occasions when he had not eaten since 7 a. m., he obtained values while still fasting at 2 p. m. He compares the average of these two fasting experiments with the average of his experiments made at 2 p. m. just after eating. This comparison is shown in table 1.

TABLE 1.—*Comparison of results obtained during fast and after food (Vierordt).*

(Values per minute.)

Conditions.	Pulse rate.	Respiration rate.	Air expired.	Carbon-dioxide output.
			c.c.	*c.c.*
Food.....	78.8	11.22	6,162	307.36
Fast.....	62.5	9.5	5,479	258.18
Difference...	16.3	1.72	683	49.18

From other experiments made when meals were taken at different times of the day, he concludes that the digestion of the evening meal proceeds with less energy than that of the noon meal. His conclusion is in part borne out by the fact that the pulse after the evening meal did not show the marked rise which was found after the noon meal.

[1]Vierordt, Physiologie des Athmens, 1845.

Although Vierordt's methods of sampling and analysis seem very crude, we find that Speck, 47 years later, quotes Vierordt as obtaining values not at all unlike those obtained by himself;[1] in fact, he confirms Vierordt's observations in that he finds the maximum carbon-dioxide excretion about 1 hour after the meal.

Böcker, 1849.—Although Vierordt was on two occasions able to compare directly the values obtained before eating with those obtained immediately after the meal, in the extensive research published by Böcker[2] in 1849 no data were obtained for the post-absorptive condition. His experiments, which were carried out with exactly the same technique as that of Vierordt, are very extended and include the ingestion of sugar, which was taken in portions usually of 1 to 3 ounces, *i. e.*, about 30 to 90 grams. Occasionally it was taken with honey, but usually with water.

The method of computation employed by Böcker is somewhat difficult to follow, for while the percentage of carbon dioxide in the expired air found by him is not unlike that commonly found, namely, 3.5 per cent, the absolute amount of carbon dioxide excreted per minute is considerably more than that ordinarily found under like conditions, varying in his own case from 445 to 589 c.c. per minute. These results were obtained by multiplying the actual values found by the factor 2.51. The found values are much more in accordance with those commonly experienced, namely, from 177 to 235 c.c., than those obtained by means of the factor.

From these imperfect experiments Böcker concludes that after the ingestion of sugar the amount of carbon dioxide produced is decreased in the ratio of 571.35 to 540.58. He records a marked increase in pulse rate after sugar ingestion. In a series of experiments made with coffee he concludes that the taking of coffee decreases both extensively and intensively the respiratory processes. In discussing the pulse rate Böcker states that he does not think there is any necessary connection between the increase or decrease in pulse rate and the increase or decrease in the production of carbon dioxide, nor does he think that the changes in the respiration rate cause a change in the carbon-dioxide production. From a series of experiments on alcohol he concludes that alcohol decreases both intensively and extensively the respiratory processes.

Smith, 1859.—Next to the few classical experiments of Lavoisier and Séguin no early research is more justly and frequently cited than is that of Edward Smith, who published two papers in 1859. In the first paper[3] he describes in detail his methods of experimentation. A mask with two valves was used, the inspired air passing through a dry gas-

[1]Speck, Physiologie des menschlichen Athmens, 1892, p. 36.
[2]Böcker, Beiträge zur Heilkunde, 1849, **1**.
[3]Smith, Phil. Trans., 1859, **149**, p. 681.

meter, and the expired air passing first through vessels containing sulphuric acid and finally through a strong solution of caustic potash to absorb the carbon dioxide. The amount of carbon dioxide exhaled was found by weighing, the total amount of ventilation being determined from the volume of air passing through the dry gas-meter. In practically all of the experiments the subject was in the sitting position. A large number of tests were made, both without and with food. In most of the food experiments a substantial mixed diet was used. In giving his results, Smith unfortunately expressed the excretion of carbon dioxide in English grains per minute,[1] but a large proportion of the original data has been recomputed by Sondén and Tigerstedt to grams per minute,[2] and presented in their excellent collection of the literature of early metabolism experiments. The average of the experiments made on himself and with three other subjects showed approximately 8.78 grains of carbon dioxide per minute for an 18-hour day with 3 to 4 meals. As the data obtained in the experiments without food gave an average value of 6.64 grains per minute, the increment after food would be 2.14 grains of carbon dioxide per minute, or 32 per cent over the fasting condition. In one observation Smith took 500 grains of arrowroot boiled in water, and found a slight increment over the fasting value. Generally the maximum quantity of carbon dioxide was observed in from 1 to 2 hours after the meal.

Since Smith found, in his first paper, that the processes of digestion with a mixed diet increased the metabolism by approximately 33 per cent, he planned the experiments reported in his second article[3] for the especial purpose of studying pure food materials. A large number of food materials of all classes were studied. Certain of Smith's conclusions are recorded herewith:

"It is evident that foods may be fitly divided into two classes, viz., those which excite certain respiratory changes (excito-respiratory), and those which do not. The excito-respiratory are nitrogenous foods, milk and its components, sugars, rum, beer, stout, the cereals, and potato. The non-exciters are starch, fat, certain alcoholic compounds, the volatile elements of wines and spirits, and coffee leaves.

"Respiratory excitants have a temporary action; but the action of most of them commences very quickly and attains its maximum within one hour.

"The most powerful respiratory excitants are tea and sugar; then coffee, rum, milk, cocoa, ales, and chicory; then casein and gluten, and lastly, gelatin and albumen. The amount of action was not in uniform proportion to their quantity. Compound aliments, as the cereals containing several of these substances, have an action greater than that of any of their elements."[4]

We can not conclude the discussion of this interesting memoir of Smith's without noting that he recognized at this early stage of research

[1] 15.432 grains equal 1 gram.
[2] Sondén and Tigerstedt, Skand. Arch. f. Physiol., 1895, **6**, pp. 101 and 143.
[3] Smith, Phil. Trans., 1859, **149**, p. 715.
[4] *Ibid.*, pp. 738–739.

some important factors which are considered at the present time as practically indispensable for successful respiration experiments. Thus, he says that there was always a short period of rest before the observations began. He states:

"We sat down at least a quarter of an hour before taking the first observation, or that which showed the state of the system before the substance under inquiry was taken, and which was the basal state with which the subsequent effects of the substance were compared, and upon the accuracy of which the truthfulness of the results mainly depended."[1]

That he recognized the importance of quietness and uniform muscular activity is indicated by the statement: "the same conditions as to posture and quietude being maintained unbroken throughout the whole inquiry." Finally, we may cite one of the conclusions from his first paper:

"There is a normal or basal line below which the system does not pass in health and wakefulness, and which is tolerably uniform. It is the same in the complete abstinence from food as at the end of the interval between meals. There is, also, when at rest, a higher point, which the system does not exceed, due to food, and it is the highest after breakfast and tea."[2]

Ranke, 1861.—The large respiration chamber constructed by Pettenkofer and Voit in Munich was apparently used for the first time with man in June 1861, for a series of experiments carried out by Ranke upon himself and published by him.[3] In these experiments the subject either fasted or was given an ordinary diet of undetermined nature, a mixed diet of known composition, or an excessive meat diet; the observations were all made in periods of 24 hours. The values are recorded in table 2.

TABLE 2.—*Carbon-dioxide production in fasting and food experiments (Ranke).*

Date.	Weight.	Character of food.	Carbon dioxide per 24 hours.
1861.	*kilos.*		*grams.*
July 10	72.68	Ordinary diet, undetermined	791.1
June 19	73.85	Mixed. Meat, bread, starch, egg, water, etc	759.5
June 21	72.87	Fasting. 2,100 c.c. water	662.9
July 2	71.79	Fasting. No water	663.5
July 24	72.57	N-free diet. Sugar, starch, fat, water	735.2
July 19	72.85	1,832 grams meat	847.5
July 16	74.22	Maximum diet, not determined; much fat, sugar, and starch	925.6

Ranke's experiments are referred to in a subsequent publication by Pettenkofer and Voit,[4] the statement being made that Ranke found in

[1] Smith, Phil. Trans., 1859, **149**, p. 717.
[2] *Ibid.*, p. 712.
[3] Ranke, Arch. f. Anat. Physiol., **1862**, p. 311.
[4] Pettenkofer and Voit, Ann. der Chem. u. Pharm., 1862–63, Suppbd., **2**, p. 53.

hunger 660 grams of carbon dioxide per 24 hours, and with the richest food 860 grams. Although the fasting value given by Pettenkofer and Voit agrees approximately with Ranke's values (see table 2), the maximum value of 860 grams is considerably less than the 925.6 grams reported by Ranke. Using 660 grams as a basal value, it is seen that the ordinary diet and the mixed diet of known composition increased the metabolism approximately 130 and 100 grams—*i. e.*, about 20 per cent—while the rich meat diet increased it nearly 200 grams and the maximum diet approximately 260 grams, or about 33 and 40 per cent respectively. Ranke's experiments are particularly interesting as representing the first 24-hour experiments made with man. They were carried out with the precautions and beautiful technique which characterize all the work done with this large apparatus by Pettenkofer and Voit, and which completely revolutionized knowledge regarding the energy transformations and gaseous metabolism of man. In a later presentation of his earlier work[1] Ranke has expressed his values in the terms of calories per 24 hours, giving approximately 2,000 calories for fasting, 2,300 calories for ordinary diet, and 2,800 calories for a rich meat diet.

Pettenkofer and Voit, 1866.—A series of 15 experiments, each 24 hours long, and made with the large respiration chamber in Munich, was reported by Pettenkofer and Voit.[2] Of 12 rest experiments, 3 were fasting, 4 were with an average diet, 2 with a protein-rich diet, 2 with a protein-free diet, and 1 with the same diet given in the morning and again in the evening. The average carbon-dioxide production per 24 hours during fast, with the subject used in most of the experiments, was 717 grams. With a mixed diet the carbon-dioxide production increased to 928 grams, an increment of 29 per cent. With a protein-rich diet the authors found that the carbon-dioxide excretion increased to 1,020 grams, which is approximately 10 per cent greater than that found with the mixed diet, but 42 per cent above the fasting value. Although the authors discuss the increments in the oxygen consumption, the errors in the method of indirect determination used make their results of questionable value. If no allowance is made for the change in the character of the materials burned under the various conditions of nutriment, we may summarize their results by stating that the ingestion of a mixed diet produced an increment in metabolism of about 30 per cent, and with a protein-rich diet resulted in an increment of about 40 per cent.

Berg, 1869.—Using an entirely different type of apparatus, Berg[3] made a large number of experiments on himself. In these experiments he employed a mouthpiece, absorption vessels, gas-meter, Müller valves,

[1]Ranke, Die Ernährung des Menschen, 1876, p. 167.
[2]Pettenkofer and Voit, Zeitschr. f. Biol., 1866, **2**, p. 459.
[3]Berg, Deutsch. Arch. f. klin. Med., 1869, **6**, p. 291.

and the Pettenkofer method for determining the carbon dioxide. Special emphasis was laid upon voluntary alteration of the type of respiration which, as we know to-day, affects most the values for the carbon-dioxide production. Nevertheless, taking into consideration only his carbon-dioxide measurements, he finds interesting values before and after food which should be noted here. Thus the carbon-dioxide production per 15 minutes, when the respiration rate averaged 15 per minute, was during fasting 8.819 grams; after a rich meal it increased to 9.960 grams, an increment of 1.141 grams, or approximately 12 per cent. An increase was also noted in the pulse rate from 65 beats per minute during fasting to 71 beats per minute after a rich meal. In the average of the experiments with normal uncontrolled respiration rate the value during hunger for the carbon-dioxide production per 15 minutes was 4.866 grams and after a rich meal 6.613 grams, an increment of 1.747 grams or about 36 per cent. The pulse rate increased from 52.4 to 61.3 per minute.

In one interesting series of experiments, the effect of water-drinking was studied. When the respiration rate was adjusted at 15 per minute Berg found practically no increase in the carbon dioxide produced with water as compared with the values found during thirst. A decrease of 3 beats per minute in the pulse rate was observed. With normal uncontrolled respiration the carbon-dioxide production increased from 5.115 to 6.519 grams per 15 minutes after water, an increment of 1.404 grams or approximately 27 per cent; the pulse rate decreased 5.8 pulse beats per minute. The author concludes that when experiments are made hourly from 7 a. m. to midnight the energy of all the respiratory functions increases after meal times. The maximum is observed 2 hours after the morning meal and 3 hours after the afternoon and evening meals. These values pertain to the experiments in which the respiration rate was controlled. With uncontrolled respiration the maximum values were noted immediately after each meal. It is clear that the artificial regulation of respiration greatly affected the values found by Berg. The results of his experiments are of interest only in substantiating practically all previous work to the effect that the increment due to the ingestion of food may be from 20 to 35 per cent.

Speck, 1873.—The possibility for change in the character of the metabolism after the ingestion of food of varying chemical composition, with consequent changes in the carbon-dioxide excretion not at all commensurate with the true changes in energy transformation, led Speck to make an extensive series of observations upon the respiratory exchange in man, in which we find the first basic determinations of oxygen consumption. By analyzing the expired air, which was collected in a spirometer, Speck was able to determine the carbon-dioxide increment and the oxygen deficit in the air passing through the lungs. From these values he computed the carbon-dioxide production and the

oxygen consumption per minute. These varied considerably with different conditions of body activity and after the ingestion of food. Speck's several papers appeared between 1865 and 1892, but were brought together and summarized by him in one publication.[1] In his earliest communication on the influence of food ingestion[2] he observed that the respiratory exchange was increased about 12 per cent by an ordinary mixed diet. In another series, published by him in 1874,[3] he reports numerous experiments with food and concludes that the respiratory exchange is increased after the noon meal 25 per cent. This marked increase in heat production, which takes place, he finds, within 30 minutes after a meal, led him to the belief that the work of digestion must cause this increased gaseous metabolism, since it is not to be expected that much food would be absorbed into the blood within the short space of 30 minutes. From the protein experiments[4] he concludes that 2 hours after the meal the height of digestion is passed and that at the end of 4 hours digestion is completed. In the sugar experiments he finds that 1 hour after the ingestion of sugar the digestion ceases. In two experiments with coffee he records a small but visible rise in the metabolism. Two experiments were made likewise on the effect of water-drinking and of flooding the body with water for some time before the experiment. According to his results, when the water is taken the evening before and to within an hour of the experiment in the morning there is no influence upon the metabolism; when the water is taken a short time before the experiment, that is, 1,250 c.c. in an hour, and the experiment is made about 30 minutes after the completion of the water-drinking, he notes a marked rise in the gaseous metabolism.

Fredericq, 1882.—By using a most ingenious apparatus, called by him an "oxygénographe," Fredericq,[5] in the laboratory at Liége, was able to determine the oxygen consumption directly on man both before and after taking food. This apparatus is a modification of an earlier form devised for animals. It is of special interest in that the oxygen is supplied to the apparatus by means of a movable bell floating in a bath of chloride of calcium solution, a principle which underlies the present universal respiration apparatus so extensively used in this and other laboratories. The carbon dioxide is absorbed by a mixture of lime and caustic soda, but the oxygen consumption is the only factor measured. Fredericq concludes that digestion is accompanied by a marked increase in the consumption of oxygen and illustrates this by several interesting curves of oxygen consumption throughout the day which show the relationship of this factor to the time in which food was

[1]Speck, Physiologie des menschlichen Athmens, 1892.
[2]Speck, Tagebl. d. 46 Vers. d. Naturf. u. Aerzte in Wiesbaden, 1873, p. 136.
[3]Speck, Arch. f. exp. Path. u. Pharm., 1874, **2,** p. 405.
[4]Speck, Physiologie des menschlichen Athmens, 1892.
[5]Fredericq, Arch. de Biol., 1882, **3,** p. 687; Éléments de Physiologie Humaine, 2d ed., 1888.

taken. In a typical experiment he finds the oxygen consumption can increase from 4.5 liters in 15 minutes (fasting) to a maximum of 6.12 liters after a meal. He lays special emphasis upon glandular activity in the work of digestion, which he thinks accounts for this increase in oxygen consumption. His results agree for the most part with those of current observations, except for showing an extraordinarily rapid return to the basal level following food. Fredericq's conclusions regarding digestion represent a very great advance and deserve to be widely quoted at the present time. His article gives one of the best considerations of digestive activity ever written.

Henrijean, 1883.—Henrijean,[1] publishing from Fredericq's laboratory, and using his apparatus, made a study of the influence of alcohol in nutrition. The experiments were made each morning at the same hour and continued 15 minutes; 5 were fasting experiments, 4 after alcohol, and 3 after food. In the food experiments bread varying in amount from 120 to 190 grams was given. The results are expressed as oxygen consumed in 15 minutes, reduced to standard conditions of temperature and pressure. Thus during fast the oxygen consumption was 3.5 liters, with alcohol 4.17 liters, and with bread 4.35 liters. From these data Henrijean concludes that the amount of oxygen consumed after alcohol or food in general is always greater than that when fasting; the increment after bread is approximately 25 per cent; after alcohol it is a little less.

Jolyet, Bergonié, and Sigalas, 1887.—Using a new respiration apparatus on a closed-circuit plan, in which the subject breathes through a hermetically sealed mask, Jolyet, Bergonié, and Sigalas[2] report two series of experiments which have a slight bearing upon the question of the influence of food. Thus, as an average of 7 experiments with the subject fasting and at rest, they found the oxygen consumption per kilogram per hour was 259 c.c. In 7 experiments with food (neither the kinds nor the amounts of food are stated) the oxygen consumption was 275 c.c. per kilogram per hour. Apparently no further experiments were made on this problem with the apparatus.

Lehmann, Mueller, Munk, Senator, and Zuntz, 1887–1893.—The first use of the Zuntz-Geppert respiration apparatus for studying the metabolism of man was in the series of observations made on the fasting subjects, Cetti and Breithaupt.[3] The study made with Cetti in March, 1887, was reported in brief by Senator and his collaborators.[4] This consisted of a fasting period of 10 days, followed by 3 days with food. The

[1]Henrijean, Bulletin l'Acad. Roy. de Belgique, 1883, sér. 3, **5,** p. 113.

[2]Jolyet, Bergonié, and Sigalas, Compt. rend., 1887, **105,** pp. 380 and 675.

[3]Although the essentials of the Zuntz-Geppert apparatus were described by Zuntz and his associates (Lehmann, Mueller, Munk, Senator, and Zuntz., Arch. f. path. Anat. u. Physiol., 1893, **131,** Supp., p. 1), the best description of the apparatus was that given later by Magnus-Levy, Arch. f. d. ges. Physiol., 1894, **55,** p. 1.

[4]Senator, Berl. klin. Wochenschr., 1887, Nr. 16, p. 290; Nr. 24, p. 425; see especially report by Zuntz and Lehmann, p. 428.

increment due to the ingestion of food was clearly shown, the authors remarking that the first meal increased the size of the combustion as a result of the stimulation to the work of digestion. One year later a second study of the metabolism during fasting was made with Breithaupt, and an extended report of the fasting experiments with both subjects was published cooperatively by Lehmann, Mueller, Munk, Senator, and Zuntz.[1] In their general consideration of the experiments on food they state:

"Im Beginn der Wiederernährung nach längerem Hungern wächst der Stoffwechsel in Folge der Verdauungsarbeit. Nachdem diese beendet, etwa 12 Stunden nach der letzten Mahlzeit beobachtet man niedrigere Sauerstoffzahlen als im Hunger. Der calorische Werth des Umsatzes ist aber eher höher, weil die Kohlenhydrate bei gleichem Sauerstoffverbrauch mehr Wärme entwickeln als Fett und Eiweiss."[2]

In the study with Breithaupt, in which the results obtained were more comparable than those with Cetti, the average total heat production for the two days of food before the fasting was 1,645 calories per 24 hours. The average of the 6 fasting days was 1,550 calories per 24 hours, the average of the fifth and sixth fasting days being 1,292 calories per 24 hours. In the 2 days with food after fasting the metabolism increased to 1,453 calories. The average heat production for two days with food, even when computed on the basis of per kilogram of body-weight, was slightly above that for the last 2 days of fasting, but not so large as the average for the 6 fasting days. It should be stated, however, that the total amount is computed from observations of relatively short duration.

Sadovyen, 1887–1888.—Sadovyen,[3] using the Pashutin respiration apparatus in St. Petersburg, made a series of food experiments before and after fasting with one subject, a man 28 years old, with a body-weight of 79 kilograms. Since the method employed was unique and the place of publication obscure, the values are abstracted in table 3. Sadovyen concludes that there is usually a slight decrease in the carbon-dioxide output during fasting and that this decrease is in proportion to the duration of fasting. His data also lead him to believe that there is no great difference between the oxygen absorbed during fasting and after food, although the general decrease in the amount of oxygen absorbed during fasting can be considered as having been established. As is to be expected, the carbon-dioxide excretion was the greatest after carbohydrates, this increase being roughly proportional to the amount of carbohydrate taken. The carbon-dioxide figures,

[1] Lehmann, Mueller, Munk, Senator, and Zuntz, Arch. f. path. Anat. u. Physiol., 1893, **131**, Supp., p. 1.
[2] *Ibid.*, p. 215.
[3] Sadovyen, Pub. Russian Soc. Gen. Hyg., 1887–88, **12**.

therefore, show very sharply the increment due to food, but the oxygen values appear to be practically unaffected by this factor.

TABLE 3.—*Respiratory exchange in food and fasting experiments (Sadovyen).*

	Character of experiment.	Per kilogram per 24 hours.	
		Carbon dioxide.	Oxygen (computed).
		gm.	*gm.*
First experiment:			
First day	Mixed diet	11.9	....
Second day	Complete fast	9.5	13.6
Third day	Same	9.6	13.0
Fourth day	Mixed diet	14.4	13.6
Second experiment:			
First day	Incomplete fast; a little tea, sugar, bread, water.	10.1	9.3
Second day	Fast with water only	10.1	11.7
Third day	Same	8.0	9.0
Fourth day	Same	8.0	12.3
Fifth day	Mixed diet	11.26	10.50
Third experiment:			
First day	Sugar and starch, amount unknown	12.1	....
Second day	Sugar, starch, water; 73 grams starch, 453 grams sugar.	13.4	10.8
Third day	Same, 115 grams starch, 352 grams sugar.	11.5	9.6

Hanriot and Richet, 1888.—Hanriot and Richet[1] published a series of observations upon the metabolism of a man before and after he had taken various foods. The apparatus used by them is in principle much simpler than any thus far devised, but unfortunately, owing to certain technical difficulties, it does not meet modern demands for accuracy. In a series of experiments from March 15 to April 1 with this subject, who weighed 50 kilograms, a mixed diet was given, consisting of bread, potatoes, beef, cheese, butter, sugar, wine, coffee, and water. The day's diet contained 268.9 grams of carbon and 20.2 grams of nitrogen. In a following series of experiments the food, somewhat less abundant, contained 230 grams of carbon. During the experiments the subject was seated and awake, but no particular attention was paid to muscular repose. The average values obtained showed that he consumed 17.5 liters of oxygen per hour fasting and 18.9 liters of oxygen per hour 1 to 5 hours after food had been consumed. The observers note that the maximum activity of the respiratory exchange occurred 3 to 4 hours after a mixed diet.

In the second paper[2] Hanriot and Richet give the results of another study of the gaseous metabolism of this man. In a 2-day fast they found that the respiratory exchange did not alter from the seventeenth to the forty-sixth hours—in other words, a base-line was reached.

[1]Hanriot and Richet, Compt. rend., 1888, **106**, p. 419. [2]*Ibid.*, p. 496.

Experiments were made with the subject fasting, with 500 grams of roast beef twice per day, with a large amount of potatoes, with glucose, and with fat (lard) and egg yolks. They conclude from this series of experiments that protein and fat modify the respiratory exchange but very little; starchy foods increase the lung ventilation and the absorption of oxygen, and especially the production of carbon dioxide. Their results show that with man during fasting there is a production per kilogram per hour of 0.5 gram of carbon dioxide and an absorption of 0.45 gram of oxygen, and that during digestion the production of carbon dioxide increases to 0.6 gram and the oxygen absorption to 0.50 gram, an increment of approximately 10 per cent.

Loewy, 1888.—In a series of experiments made by Loewy[1] in Zuntz's laboratory and primarily designed to study the influence of unoxidizable material (Glauber salts) in the intestinal tract, two experiments were made with water. In one it was found that 11 minutes after the subject had taken 100 grams of water the oxygen consumption increased from 218.5 c.c. to 221.8 c.c. per minute, an immaterial increase. Later (33 minutes after drinking the water) the oxygen consumption had increased to 232.2 c.c.—*i. e.*, an increment of 14 c.c. of oxygen, or approximately 6 per cent. In another experiment, 10 minutes after taking 100 grams of water, the oxygen consumption increased from a basal value of 221 c.c. per minute to 226 c.c. per minute, an increment of only 5 c.c. of oxygen. Approximately half an hour later the oxygen consumption had increased to 242 c.c. per minute. Since no graphic record of the activity accompanied these experiments—an omission which has been criticized[2]—it is difficult to state with certainty whether or not the ingestion of water actually produced a measurable increase in the metabolism.

Marcet, 1889.—Marcet[3] reported the results of a series of experiments with two subjects, which were designed primarily for a study of the influence of food. The general conclusions confirm the results of previous observations on the influence of food upon the carbon-dioxide production, namely, that the maximum amount occurs between 2 and 3 hours after the meal and the minimum amount just before breakfast.

Marcet, 1891.—Later, Marcet[4] published the results of a series of experiments on himself and his assistant, Russell, in which 6 experiments were made on each subject, about 2 hours after food, and 6 experiments during "fast," *i. e.*, 4 hours after breakfast. Each experiment lasted 7 to 8 minutes. The subject, reclining in a steamer chair, inhaled through the nose and exhaled through the mouth, sometimes closing the nostrils with the fingers when necessary. The expired air

[1]Loewy, Arch. f. d. ges. Physiol., 1888, **43**, p. 515.
[2]Benedict and Emmes, Am. Journ. Physiol., 1912, **30**, p. 197.
[3]Marcet, Proc. Roy. Soc., 1889, **46**, p. 340; also, Phil. Trans., 1890, **181**, ser. B, p. 1.
[4]*Ibid.*, 1891–92, **50**, p. 58.

was collected in a bell-jar suspended over salt water. The carbon dioxide was determined by titrating according to the method of Pettenkofer; the oxygen was determined by explosion with hydrogen. With himself, Marcet found that the oxygen consumed during digestion was 21.37 grams per hour as compared with 20.26 grams during fasting. The carbon-dioxide excretion also showed the influence of food. With his assistant, even a greater increment in the oxygen consumption per hour and per kilogram per hour was noted after food than with Marcet.

Marcet, 1892.—Another set of experiments was made by Marcet[1] with a slightly modified apparatus which permitted the direct determination of the amount of the inspired air. One of the subjects was Marcet himself, 64 years of age, and the other Smith, aged 23 years. With Smith 6 fasting experiments 5 hours after breakfast and 14 food experiments were made with environmental temperatures ranging from 12.9° to 22.2° C. The average values obtained for a period of 8 to 9 minutes were as follows: With food the oxygen consumed was 280 c.c. and the carbon dioxide produced 229 c.c.; during the fast the oxygen consumed was 250 c.c. and the carbon dioxide produced 216 c.c. Comparing the values obtained on himself and Russell in 1891 with these values obtained on himself and Smith, Marcet draws the following conclusions:

"The influence of food on the interchange of respiratory gases, although being attended with a rise in the oxygen consumed and carbonic acid expired, apparently varies with reference to the oxygen absorbed. Young and strong persons, requiring a full allowance of food, appear to absorb more oxygen while under the influence of a meal than while fasting, but late in life the oxygen absorbed appears to show little or no tendency to increase after a meal."[2]

In 1895 Marcet maintained in a Croonian lecture that the "period of the maximum consumption of oxygen is, undoubtedly, within the first hour after a midday meal."[3] He concludes that with young men there is distinctly more oxygen absorbed 2 hours after a full meal than during a fast. In this discussion he used the results obtained in his experiments in 1891 and 1892.

Hanriot and Richet, 1891.—In an extended series of observations on a single subject, Hanriot and Richet,[4] employing essentially the same apparatus as in their earlier researches, studied the influence of food and fasting upon a subject 48 years old who weighed about 50 kilograms. Two and three determinations per day were made for about $3\frac{1}{2}$ months. The average value for the carbon-dioxide excretion per kilogram and per hour in 36 fasting experiments was 0.492 gram; in 86 experiments

[1]Marcet, Proc. Roy. Soc., 1892–93, **52,** p. 213.
[2]*Ibid.*, p. 224.
[3]Marcet, A contribution to the history of the respiration of man. Croonian Lectures delivered before the Royal College of Physicians in 1895, p. 28, 1897.
[4]Hanriot and Richet, Ann. de Chim. et de Phys., 1891, sér. 6, **22,** p. 495.

with food the average carbon-dioxide excretion increased to 0.569 gram. The authors conclude that after a mixed diet or a diet composed of carbohydrates a greater excretion of carbon dioxide with a more active ventilation begins about an hour after the ingestion of food and reaches its maximum from $2\frac{1}{2}$ to $3\frac{1}{2}$ hours afterwards.

Zuntz and Magnus-Levy, 1891.—In studying the digestibility and nutritive value of bread, Zuntz and Magnus-Levy,[1] employing a Zuntz-Geppert respiration apparatus, made a number of experiments on themselves, not only in the post-absorptive condition but likewise after 250 to 300 grams of bread and 60 grams of butter. Although recognizing the fact that their data need amplification, they tentatively conclude that bread causes a fairly considerable increase in the oxygen consumption, the increase in the first hour amounting to about 25 per cent of the fasting value. Subsequently the oxygen consumption decreases and at the end of 3 to 5 hours reaches practically the basal value. They further conclude that, in general, the increase above the fasting value is, with bread, about 15 per cent during the first 6 hours, but that on the 24-hour basis the increase due to digestion would be not less than 10 per cent of the total oxygen consumed during rest. Frequently, in reporting an increase due to metabolism, writers confuse an increase obtained for a short time, *i. e.*, a "peak" increase, with that obtained in a 24-hour period. Apparently Zuntz and Magnus-Levy were the first to make a sharp distinction between these increases. This practice could well be followed by modern writers.

Hanriot, 1892.—The interesting series of observations on the effect of taking glucose, reported by Hanriot in 1892,[2] are of greater significance as regards the influence upon the respiratory quotient than as to the effect upon the total metabolism. Hanriot's paper emphasizes the fact that the respiratory quotient may attain a value as high as 1.30. Under these conditions there is a transformation of carbohydrate into fat, and the values do not lend themselves easily to a computation of the increased metabolism due to the digestion of the glucose, for apparently the oxygen values determined by Hanriot are given with some reserve.

In Hanriot's article published in 1893,[3] which is a continuation of his first paper published in 1892, emphasis is laid primarily on the respiratory quotient and on the transformation of carbohydrates into fat. Of special interest in view of our own contrary findings is Hanriot's statement that with 50 grams of glucose dissolved in 500 c.c. of water the quotient always rises to about 1.25. The paper concludes with an extensive discussion of the theoretical points involved in the transformation of carbohydrate into fat.

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[1]Zuntz and Magnus-Levy, Arch. f. d. ges. Physiol., 1891, **49**, p. 438.
[2]Hanriot, Compt. rend., 1892, **114**, p. 371.
[3]Hanriot, Arch. de Physiol., 1893, **25**, p. 248.

Likhatscheff, 1893.—Likhatscheff,[1] describing the Pashutin respiration calorimeter for man, cites the results of three food experiments and one fasting experiment, the latter being made for the specific purpose of providing a basal value for the study of the influence upon metabolism of taking food. Since this represents the first experiments on man in which direct calorimetry was applied, and direct measurements of carbon-dioxide production and indirect measurements of oxygen consumption were made simultaneously, the results are given in table 4.

TABLE 4.—*Metabolism in food and fasting experiments (Likhatscheff).*

Experiment No.	Condition.	Per kilogram and per 24 hours.		
		Heat.	Carbon dioxide.	Oxygen (calculated).
		calories.	*grams.*	*grams.*
1	Normal.	33.07	12.48	11.28
4	Do.	37.39	14.21	13.62
5	Do.	34.44	12.22	13.27
6	Hunger.	31.83	10.68	11.46

Here it is seen that on at least 2 of the 3 days with food the oxygen consumption was materially higher than that on the fasting day. The author finds that the curves for heat production and gaseous exchange reach their highest point during the day and their lowest point at night. Since both of these factors are complicated by the small incidental muscular movements during the day, the diurnal variations can not be ascribed to digestive processes alone.

d'Arsonval, 1894.—In reporting the tests of his anemo-calorimeter, d'Arsonval[2] gives the results of an experiment on himself (weight 74 kilograms, age 42 years), in which the heat output per hour, when he was standing dressed and fasting, was 79.2 calories. One hour after breakfast (the kind and amount of food not given) the metabolism under the same conditions of standing with clothing rose to 91.2 calories, an increment of approximately 18 per cent.

Magnus-Levy, 1894.—Recognizing clearly the fact that the increment in metabolism following the ingestion of food persists only a relatively short time, Magnus-Levy,[3] employing the Zuntz-Geppert respiration apparatus, carried out a most extended series of experiments on the influence of food on metabolism. Certainly no series of experiments prior to 1894 is comparable to this research, and few since that time can compare with it for accuracy or for skillful plan. Considering only those experiments made with men, we find that most of the

[1]Likhatscheff, Production of heat of healthy man in the condition of comparative rest. Diss., St. Petersburg, 1893.
[2]d'Arsonval, Arch. de Physiol., 1894, **26,** p. 360.
[3]Magnus-Levy, Arch. f. d. ges. Physiol., 1894, **55,** p. 1.

experiments were carried out with one subject. An extensive list of basal values is reported, these values being, for the most part, very constant. Since it is necessary to consider the time element in experiments of this kind, Magnus-Levy carefully determined the basal metabolism throughout the day on three subjects and found it relatively constant, the values for the oxygen consumption falling approximately 5 per cent during the day.

Food experiments were made on 3 days with fat, the diet on one day being 210 grams of bacon, 30 grams of bread, and 8 c.c. of alcohol; on another day 210 grams of butter; and on a third day 100 grams of bacon. A small increase in the metabolism was noted, particularly in the later hours. In the first two experiments the increment in the oxygen consumption was from 10 to 14 per cent. In the last experiment the maximum value was but 6 per cent above the basal value.

In carbohydrate experiments carried out with four subjects, white bread was chiefly used, but one experiment was also made with pumpernickel. The increment in the oxygen consumption was positive in practically all cases. It was found that the increment in the first hour may be as high as 33 per cent; in three cases it was over 6.5 per cent even 7 hours after taking food. Eight experiments were made on man after giving from about 50 to 155 grams of cane sugar or grape sugar. The oxygen consumption, which alone may be used in measuring the increase in the total metabolism, showed in all but one case an increase during the first hour, this increase amounting in one instance to 16 per cent. In subsequent hours the values were frequently below the basal value, particularly when small amounts of sugar were given. With 100 or more grams of sugar oxygen values above basal were found; in one experiment the increment persisted for 8 hours.

Five observations were made on man after roast beef had been given in amounts varying from 120 to 310 grams. In all of the experiments the percentage increase in the oxygen consumption was very marked, the maximum occurring between the third and sixth hours. In at least three instances the increment was 20 per cent or over as late as the seventh or eighth hour, showing a marked and prolonged effect as a result of the ingestion of protein.

Three experiments were made in which the subject took a mixed diet which supplied 3,060, 2,280, and 2,150 calories, respectively. In practically all instances about 47 per cent of the energy came from carbohydrate, 33 per cent from fat, 14 per cent from protein, and 6 per cent from alcohol. The increase in the oxygen consumption was marked in nearly every case. Thus, after breakfast, the average percentage increments for 4 successive hours were 27, 27, 16, and 6 per cent, respectively; after the noon meal for 6 successive hours they were 40, 35, 27, 19, 17, and 9 per cent, respectively; after the evening meal

they were 33, 23, 12, and 6 per cent for the first 4 hours, followed by slightly negative values for the remainder of the night. The average increment for the 14 hours from the first hour after breakfast until the fourth hour after the evening meal is computed as 21 per cent. The author points out that the true metabolism is really somewhat greater, since the mechanical work of chewing and swallowing is not noted in the experiments. An interesting computation is made of the total increment for the entire day, which is computed to amount to 13 per cent for the oxygen consumption and 19.75 per cent for the carbon-dioxide production.

This article, which is justly cited as a classic, represents by far one of the most critical and ambitious attempts to solve the perplexing problem of the influence of the ingestion of food upon the metabolism of human subjects. The observations on men are substantiated by even more extensive series of observations on dogs. The dominant note of the discussion is that the increase following the ingestion of food is in large part due to the work of digestion in contradistinction to the explanation of it by Rubner's theory of specific dynamic action. On the other hand, Magnus-Levy's discussion of the subject has the great advantage of giving a concrete statement as to the probable cause for the increased metabolism and consequently is more subject to direct experimental attack than is the more subtle explanation offered by the specific dynamic action theory, which in itself has undergone marked revision in recent years.

Sondén and Tigerstedt, 1895.—The extensive research carried out by Sondén and Tigerstedt[1] with the large respiration chamber in the Karolinska Institute in Stockholm does not lend itself particularly well to a discussion of the influence of the ingestion of food, inasmuch as in practically all of the experiments the subjects indulged in more or less muscular activity, and in relatively few cases were there controlled periods of fasting; furthermore, only the carbon-dioxide production was determined. As a result of the comparison of the data obtained in the evening experiments and experiments on the following morning, the authors concluded that the carbon-dioxide production in the morning experiments was about 14 per cent lower than that in the evening experiments.

Falloise and Dubois, 1896.—Falloise and Dubois,[2] collecting expired air in a rubber bag and analyzing the air by the Hempel method, made a number of fasting experiments 15 hours after food and obtained an average respiratory quotient of 0.71. In the food experiments, a mixed diet was first given and the respiratory quotient was studied every half hour for 3 hours after the meal. With this diet the respiratory

[1]Sondén and Tigerstedt, Skand. Arch. f. Physiol., 1895, **6**, p. 1.
[2]Falloise and Dubois, Travaux du Lab. de L. Fredericq, 1893–95, **5**, p. 147; Arch. de Biol., 1896, **14**, p. 457.

quotient reached its highest point in 2 hours. Falloise and Dubois then studied the quotient 2 hours after a meal predominating in fat; abnormally low respiratory quotients were obtained. Two hours after the ingestion of 60 grams of glucose the authors found that the quotients tended to approach unity but never quite reached it, the average of 6 experiments 2 hours after 60 grams of glucose giving a quotient of 0.90. The oxygen consumption with a basal value of 4.85 c.c. per kilogram per minute rose to 5.16 c.c. 2 hours after a mixed diet, and to 4.4 c.c. and 4.6 c.c. in experiments 2 hours after a fat diet and 2 hours after 60 grams of glucose, respectively. The fact that the last two series of observations gave values lower than the basal value throws considerable doubt upon the accuracy of the experiments.

Johansson, Landergren, Sondén, and Tigerstedt, 1897.—In their research on metabolism during fasting, Johansson, Landergren, Sondén, and Tigerstedt,[1] using the large Sondén-Tigerstedt respiration chamber in Stockholm, planned the experiments in such a way that comparisons showing the influence of food were readily made. Thus, with characteristic foresight, the research was planned to include 2 days with usual diet, 5 days of fasting, and finally 2 days with the ordinary diet. The carbon-dioxide excretion was determined in 11 successive 2-hour periods and careful analyses were made of the food and excreta. Since on the first food day the carbon-dioxide production was determined for only the night period, there remain but 3 food days of 22 hours each that can be used for comparison. The food consisted of bread, butter, cheese, meat, beer, milk, potatoes, bouillon, etc., with a protein content per day varying from 148 to 223 grams, a fat content of 238 to 263 grams, and a carbohydrate content of 261 to 283 grams. The separation of the carbon-dioxide production into periods of awake and asleep shows that these authors recognized thus early the significance of securing the most advantageously comparable periods, namely, when there was complete muscular repose during sleep. The average values given for the carbon-dioxide production per 2-hour period for the 9 days are shown in table 5. Since the carbon-dioxide production was determined in 2-hour periods, it was possible to study the diurnal variations. The average values found for these periods on the food days and fasting days are therefore compared in table 6.

TABLE 5.—*Carbon-dioxide production after food and during fast (Johansson and associates).* (2-hour periods.)

Day of experiment.	Awake.	Asleep.
Food:	*grams.*	*grams.*
First	....	56.0
Second	83.3	60.0
Eighth	77.0	50.4
Ninth	73.5	49.0
Fast:		
Third	66.0	40.8
Fourth	61.1	42.0
Fifth	57.0	44.0
Sixth	57.7	40.0
Seventh	57.0	37.9

[1]Johansson, Landergren, Sondén, and Tigerstedt, Skand. Arch. f. Physiol., 1897, **7**, p. 29.

In a discussion of the results the authors consider the total metabolism per kilogram on the fifth fasting day as equal to 100, and state that the metabolism during the food days is 128.4, 122.0, and 117.8 per cent of the basal value respectively. They recognize that the low values found during fasting may perhaps be ascribed to decreased muscular movement due to the weakened condition of the subject. They also point out that this decrease in the carbon-dioxide production is observed during sleep, for on the food days the average carbon-dioxide production per kilogram in sleep is 35.4 per cent greater than the corresponding average value on the fifth day of fasting, while the minimum value is 43.4 per cent greater than the corresponding minimum value during the fifth day of fasting. In discussing the bearing of these experiments upon the problem of the dynamics of digestion the authors state:

"In wie fern dies, wie es sich Lehmann und Zuntz vorstellen, von der Verdauungsarbeit herrührt oder ob die Zufuhr von Nahrung in der That den Stoffwechsel erhöht, darüber giebt uns der vorliegende Versuch keine bestimmten Anhaltspunkte."[1]

Basing the discussion of the energy transformations wholly upon the carbon-dioxide production is of course open to the serious objection that in many instances we may have a simple protein-fat katabolism replaced by a katabolism consisting essentially of carbohydrate, thus increasing enormously the carbon-dioxide production without a corresponding increase in the total energy transformations. Nevertheless it is clear that in these experiments there was a great increase in the metabolism on the food days.

TABLE 6.—*Average diurnal variations in carbon-dioxide production after food and during fast (Johansson and associates).* (Values in grams.)

Time.	Food.	Fast.
10 a. m. to 12 a. m....	78.0	54.8
12 a. m. 2 p. m....	80.1	57.2
2 p. m. 4 p. m....	70.0	54.1
4 p. m. 6 p. m....	81.2	57.8
6 p. m. 8 p. m....	82.0	59.5
8 p. m. 10 p. m....	78.0	66.4
10 p. m. 12 p. m....	78.1	[1]46.5
12 p. m. 2 a. m....	[1]54.0	[1]37.5
2 a. m. 4 a. m....	[1]53.0	[1]39.1
4 a. m. 6 a. m....	[1]54.5	[1]40.7
6 a. m. 8 a. m....	81.3	68.6

[1]Obtained during sleep.

Laschtschenko, 1898.—To study the influence of water-drinking upon the carbon-dioxide output of the body in man, Laschtschenko,[2] working in Rubner's Institute in Berlin and employing the Rubner modification of the Pettenkofer-Voit chamber, made a series of experiments on himself as subject. Each experiment lasted about 5 hours, during which the subject read but was otherwise in complete muscular repose. Water was taken in 250 c.c. portions at regular intervals to the amount of 2 liters, the last portion being drunk an hour before the end of the

[1]Johansson, Landergren, Sondén, and Tigerstedt, Skand. Arch. f. Physiol., 1897, **7**, p. 61.
[2]Laschtschenko, Arch. f. Hyg., 1898, **33**, p. 145.

experiment. Since the experiments were designed to study likewise the influence of environmental temperature, a number were made at a temperature of 17.3° to 19.1° C., others at 31.9° to 32.7° C., and some at 37.4° to 37.6° C. The author concludes that at room temperature, 17° to 19° C., there is no effect on the carbon-dioxide production as the result of drinking water. At a temperature of 31° to 32° C. there is a very slight increase in the carbon-dioxide production. At a temperature of 37° C. the data are negative.

Jaquet and Svenson, 1900.—Although Jaquet and Svenson[1] worked with obese subjects, their experiences are not without interest. Using the Zuntz-Geppert respiration apparatus and making experiments at least 12 hours after the last meal, they studied the effect of a meat diet, also of a mixed diet consisting of coffee, milk, bread, butter, meat, rice, wine, potato, and carrots. The average fasting values found lie within the normal limits obtained by other investigators. From the food experiments the authors conclude that the increase in the combustion processes caused by the ingestion of food is decidedly less and of shorter duration with these three obese individuals than with normal men.

Koraen, 1901.—Using precisely the same respiration apparatus as Sondén and Tigerstedt, Koraen[2] in 1901 published under the direction of Johansson a series of observations on himself to study the influence of the ingestion of various kinds of foods. In these experiments special care was taken to secure muscular repose. The series consisted of 6 fasting experiments, 6 with the ingestion of 65.6 grams of fat, 6 with 160 grams of cane sugar, and 8 with 215 grams of cooked ham which supplied about 52 grams of protein. In 6 other experiments a mixed diet, consisting of 250 grams of uncooked carrots, 125 grams of rye bread, and 20 grams of butter, was used. The author concludes that the total metabolism shows no increase after the ingestion of about 66 grams of fat, rises somewhat after the ingestion of about 165 grams of cane sugar, and increases markedly after 52 grams of protein. A marked increase was also noted after the ingestion of the mixed diet. After the ingestion of protein the basal value was not reached until about the seventh hour, but after the ingestion of the mixed diet it was reached about the fifth hour.

Zuntz and Schumburg, 1901.—In their well-known study on the physiology of walking, Zuntz and Schumburg[3] report a few experiments with their two subjects which may be used for noting the influence of the ingestion of food. They record that with one subject the noon meal resulted in an increase in the oxygen consumption of 22 per cent and with the other 20.5 per cent.

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[1]Jaquet and Svenson, Zeitschr. f. klin. Med., 1900, **41**, p. 375.
[2]Koraen, Skand. Arch. f. Physiol., 1901, **11**, p. 176.
[3]Zuntz and Schumburg, Physiologie des Marsches, 1901.

Rubner, 1902.—For the purpose of this discussion the majority of the remarkable experiments carried out by Rubner are not available for comparison purposes, since his researches were for the most part with animals, particularly dogs, and in only a few instances with men. He does, however, report a series of experiments[1] in which the first day was a 24-hour fasting experiment, on the second day the subject ate a large amount of meat, on the third day he did work, on the fourth day he received 600 grams of cane sugar, and on the last day he performed work on a sugar diet. A preliminary report of this experiment was made in abstract form in 1902.[2] Using the later values, which probably have a greater degree of accuracy, we find that the heat production per 24 hours at rest was, during fasting 1,976 calories, with sugar 2,023 calories, and with protein 2,515 calories. The surprising feature of this experiment is the fact that the ingestion of 600 grams of cane sugar and 3,000 c.c. of water produced an increase in the heat production of only 2.4 per cent; the ingestion of protein, on the other hand, resulted in an increase in the heat production of 27.2 per cent.

Reach, 1902.—In connection with an investigation on rectal feeding, Reach[3] made 2 experiments, each with 60 grams of dextrose, and 3 experiments with 60 grams of cane sugar, the sugars being given *per os*. The subject was a man 27 years old, who was suspected of suffering in a slight degree from hypothyroidism. Reach concludes from these experiments that after the ingestion of 60 grams of dextrose the respiratory quotient immediately rises. He found in the 2 experiments with dextrose that the maximum increase in the quotient appeared in the second hour, being 0.087 and 0.101, respectively, above the basal values of 0.792 and 0.715. After 60 grams of cane sugar the rise in the respiratory quotient was more rapid, the increment above the basal values of 0.821, 0.886, and 0.768 in the 3 experiments being 0.104, 0.104, and 0.107, respectively. The values for the oxygen consumption are also given for 2 of the cane-sugar experiments and one of the dextrose experiments. With cane sugar they show a marked and constant increment in the oxygen consumption of approximately 15 to 20 per cent and with dextrose a rapid rise of 20 per cent, followed by an almost immediate fall to the basal value.

Johansson and Koraen, 1902.—Employing essentially the same experimental methods as those used in former researches, and laying special emphasis upon the simultaneous effects of muscular work and the ingestion of food upon metabolism, Johansson and Koraen[4] studied the influence of the two factors separately, using the food materials sugar, olive oil, and eggs. Although based only upon carbon-dioxide deter-

[1]Rubner, Sitzber. K. Preuss. Akad. Wiss., 1910, Part 1, p. 316.
[2]Rubner, Die Gesetze des Energieverbrauchs bei der Ernährung, 1902.
[3]Reach, Arch. f. exp. Path. u. Pharm., 1902, **47**, p. 231.
[4]Johansson and Koraen, Skand. Arch. f. Physiol., 1902, **13**, p. 251.

minations and thus liable to the errors which may be ascribed to this method of computation, the results of these studies are of unusual importance. Johansson and Koraen conclude that when a certain amount of muscular work is performed the increase in the basal metabolism is a definite value and the increment due to food is independent of the increment due to muscular work—that is, food of the same amount and composition produces a like increase in the metabolism, irrespective of whether the subject is at rest or doing work. The ingestion of carbohydrates apparently produced the same increase in the carbon-dioxide output with muscular work as with complete rest; protein likewise gave the same effect during rest as during work; practically no increment was found with olive oil. The paper concludes with interesting theoretical discussions in which the authors contend that the ingestion of food produces an increase in the carbon-dioxide production not by reason of an increased work of digestion, but because of an influence upon the metabolism of the food after its absorption.

Atwater and Benedict, 1903.—Although a large number of resting metabolism experiments with food were made with the calorimeter at Wesleyan University, Middletown, by Atwater and his associates, but one series lends itself for comparison. Experiments Nos. 35 and 36 with subject J. C. W., reported by Atwater and Benedict,[1] were carried out December 9 to 14, 1900. In these two experiments the subject remained continuously in the chamber. In the first experiment of 4 days the daily diet consisted of 100 grams of beef, 25 grams of butter, 850 grams of milk, 300 grams of bread, 50 grams of breakfast cereal, 50 grams of crackers, and 20 grams of sugar, with a total heat of combustion of 2,519 calories per day. The determined heat output per day was 2,397 calories. The fifth day of the experimental series was a complete fast. On this day the heat determined was 2,253 calories, or 144 calories less than that on the food days. The increment due to digestion may therefore be estimated as approximately 6 per cent on the 24-hour basis.

Reach, 1904.—In experiments with a 15-year old obese boy, in which the method of Zuntz and Geppert was used, Reach[2] found that the oxygen consumption after a meal was much less than was commonly experienced. This is in harmony with results obtained in earlier experiments made by Jaquet and Svenson[3] on obese individuals.

Johansson, Billström, and Heijl, 1904.—In continuation of the interesting studies carried out in Johansson's laboratory on the influence of the ingestion of carbohydrates upon the carbon-dioxide excretion,

[1]Atwater and Benedict, U. S. Dept. Agr., Office Exp. Sta. Bull. No. 136, 1903.
[2]Reach, Salkowski-Festschrift, 1904, p. 319.
[3]Jaquet and Svenson, Zeitschr. f. klin. Med., 1900, **41**, p. 375. On the contrary, results obtained later by Haussleiter (Zeitschr. f. exp. Pathol. u. Therapie, 1915, **17**, p. 413) lead him to infer that the increase in the metabolism after the ingestion of food in obesity is not less than with normal individuals, but the falling off in the curve is evidently retarded.

Johansson, Billström, and Heijl[1] report respiration experiments with men in which cane sugar, dextrose, and levulose were used. Following the usual Stockholm technique, the sugars were taken in varying amounts with varying quantities of water. The carbon-dioxide output at first seemed to increase proportionately with the amount of sugar taken. With larger portions, *i. e.*, 200 grams of cane sugar, the increase was relatively smaller. Cane sugar and levulose had about the same effect, while dextrose had a much smaller effect than either levulose or cane sugar. In an attempt to explain the difference between levulose and dextrose the authors assume that the rapidity of combustion is greater and the rapidity of storage as glycogen less for levulose than for dextrose. They conclude that the ingestion of carbohydrates actually increases the energy transformation, unless it is assumed that there is a fat formation with a cleavage of carbon dioxide.

Cronheim, 1905.—Employing the Zuntz-Geppert technique, Cronheim[2] reports the study of the influence of a highly nitrogenous (81.2 per cent protein) preparation, somatose, upon the metabolism. He concludes that the increased metabolism after somatose, designated by him in accordance with the usage of the Zuntz school as *Verdauungsarbeit*, is less than that after meat containing a corresponding amount of nitrogen. A number of meat experiments are reported in which he finds that after 130 grams of meat the increase in the oxygen consumption in 7 hours equals 5,790 c.c., corresponding to a total energy output of 27.73 calories, or 20.9 per cent of the energy value of the meat. With an amount of somatose containing as much nitrogen as the 130 grams of meat, he finds that the increase was but 9.29 per cent of the energy of the ingested material. With meat the main increase in metabolism occurred in the second to the fourth hour, but with somatose it did not occur until later. These time relations were likewise observed in the rate of excretion of nitrogen in the urine.

Johansson, 1908.—In 1908 Johansson[3] made another important contribution to the study of the influence of carbohydrates upon metabolism. Using the Sondén-Tigerstedt respiration chamber in Stockholm with a large number of subjects, he made experiments with various sugars and accurately determined the increment in the carbon-dioxide production. It is greatly to be regretted that Johansson's most valuable discussion could not have been based upon measurements of the oxygen consumption made simultaneously with the carbon-dioxide measurements. In this way a suggestion could have been obtained as to the probable relationship between the three factors which may enter into such a carbon-dioxide increment, *i. e.*, first, the substitution of a katabolism consisting mainly if not exclusively of carbohydrate; second,

[1]Johansson, Billström, and Heijl, Skand. Arch. f. Physiol., 1904, **16**, p. 263.
[2]Cronheim, Arch. f. d. ges. Physiol., 1905, **106**, p. 17.
[3]Johansson, Skand. Arch. f. Physiol., 1908–09, **21**, p. 1.

an excess of carbon dioxide produced in the transformation of the excess carbohydrate into fat; and third, the actual increment in the carbon-dioxide production due to an increased total metabolism. Although Johansson did not take into account all of these three factors, certain of his conclusions are important.

An increment in the carbon-dioxide production was found with all sugars, this being greatest with levulose and sucrose and least with dextrose. For each sugar the maximum increase was obtained with about 150 grams; the length of the increase never exceeded 6 hours, which corresponds to the time required for the passing of food through the small intestine. Levulose gave twice as great an increase in the carbon-dioxide excretion as did the same amount of dextrose. Johansson contends that the increase in carbon dioxide after the ingestion of sugar can not be satisfactorily explained on the assumption of a *Verdauungsarbeit.* The maximum capacity of the intestine for absorbing sugar averages about 80 grams per hour. The maximum carbon-dioxide output following the feeding of cane sugar and levulose was about 35 grams per hour, with a basal value of 22 grams. With dextrose and milk sugar the increment was only about one-half that with the other sugars. A series of experiments in which sugars were given with varying amounts of water led Johansson to the conclusion that the ingestion of water played no rôle in the metabolism, since the increase in carbon dioxide was entirely independent of the amount of water consumed.

Staehelin, 1908.—In a series of observations on an obese individual, Staehelin,[1] using the Zuntz method for determining the oxygen consumption and carbon-dioxide production, found that the increment after eating meat was very much less than that found with normal individuals. He reports 3 experiments *nüchtern,* 2 experiments with a meat diet, 2 with a diet of cabbage, potatoes, and apples, and 2 with bacon, bread, and butter. Staehelin concludes that the vegetable diet, because of the increased work of digestion, results in an increase in the oxygen consumption, while a cellulose-poor diet (fat diet) has no noticeable effect. He concludes that the *Verdauungsarbeit* may be likewise recognized with obese individuals.

The oxygen consumption after food was determined by Staehelin[2] with the chamber method in 5 experiments on himself and 2 on tubercular patients. These experiments, made with the Jaquet respiration chamber in the Basel clinic, are of particular interest, since Staehelin attempted to minimize muscular activity and to secure uniformity in conditions by carrying out experiments in the night, when the subject slept for a greater part of the time. The importance of securing observations with the subject asleep and in complete muscular repose

[1]Staehelin, Zeitschr. f. klin. Med., 1908, **65**, p. 425. [2]*Ibid.*, **66**, p. 201.

has recently been especially emphasized by many workers in metabolism. The experiments were somewhat complicated by the facts that the basal values were obtained but 6 or 7 hours after taking food rather than the customary 12 hours, and that in all the food experiments the metabolism had not reached the basal value 12 hours after the food was taken. Nevertheless, the results are of great significance in indicating the usual enormous increase in metabolism due to protein ingestion which, in one instance, corresponded to an increase of practically two-thirds of the caloric value of the protein ingested. In both the fat and carbohydrate experiments the increases were much larger than would commonly be expected, even though the caloric value of the material ingested was in both cases much greater than that of protein. In the observations on the tubercular patients Staehelin found similar increases. With one patient there was a very much greater increase after protein than with normal individuals, thus suggesting to Staehelin that the protein ingestion has a specific influence upon tubercular patients.

von Willebrand, 1908.—Although the observations were carried out on obese patients rather than on normal individuals, the experiments of von Willebrand[1] are of interest, since he studied the metabolism both before and after the ingestion of sugar and protein. The experiments have the single defect of the experiments made with the Sondén-Tigerstedt chamber in that the oxygen consumption was not determined and the conclusions with regard to energy transformations are accordingly based upon the carbon-dioxide excretion. This was found for obese patients to be similar to the increase noted with healthy persons, and von Willebrand concludes that the increase in metabolism after food is just as great with obese as with normal individuals. The fact that two of the subjects showed a relatively slight increase after protein is less significant because of his statement that all of his subjects were not as well trained to complete muscular repose as were those of Koraen.

Durig, 1909.—With the accuracy characteristic of all his work, Durig[2] reports a series of experiments made in Vienna and on Monte Rosa, in which sugar was given, the main object of the experiments being to study the influence of altitude upon the rise in metabolism following the ingestion of sugar. The logical method of securing basal values immediately preceding sugar was followed in all cases. In one of the Vienna experiments, after 120 grams of glucose the heat output increased from an average of 1.032 calories per minute to a maximum of 1.338 calories in the first hour after the ingestion of sugar. At the end of 5 hours the metabolism was still approximately 6 per cent above the basal value. In one of the Monte Rosa experiments the heat out-

[1]von Willebrand, Skand. Arch. f. Physiol., 1908, **20**, p. 152.
[2]Durig, Denkschr. d. Wiener Akad. d. Wiss., 1909, **86**, p. 116.

put increased after the same amount of sugar from a basal value of 1.257 calories per minute to a maximum of 1.463 calories in the first hour after feeding. In the fourth hour the basal values were again reached. The respiratory quotients did not exceed unity in any case.

Gigon, 1909.—An important contribution from the Stockholm laboratory on the influence of protein and carbohydrate ingestion upon metabolism was published by Gigon[1] in 1909. Since it is well established that both sugar and protein cause an increase in the carbon-dioxide production, the experiments were especially designed to study the influence of a combination of sugar and protein. As was usual with the experiments in the Stockholm laboratory, the carbon-dioxide excretion alone was determined. The fasting value was found to be 23.8 grams carbon dioxide per hour. After 46 grams of dextrose this increased to 29.9 grams, and in experiments with 16 grams casein it increased to 28 grams. When these same amounts of dextrose and casein were given together, the carbon dioxide rose to 34 grams. Since the increase in the carbon-dioxide production in the last series of experiments was practically the sum of the increments noted in the dextrose and casein experiments, the author concludes that there is a summation effect. Furthermore, if carbohydrate or protein is taken in several equal amounts at regular intervals, the increased carbon-dioxide production remains at an unchanged height for several hours. The author concludes with an interesting discussion of the *Verdauungsarbeit* and the specific dynamic action theories, defending the latter.

Gigon, 1911.—The most extended discussion of the influence of food on the metabolism of man since the research of Magnus-Levy was contributed by Gigon in 1911.[2] His research, which was carried out with himself as the only subject, and exclusively with pure food materials, was made in part with the Sondén-Tigerstedt respiration chamber in Stockholm, and in part with the Jaquet respiration chamber in the Medical Clinic in Basel. A few basal metabolism experiments,[3] but no food experiments, were made with a respiration apparatus employing the mouthpiece, Müller valves, and spirometer in the Poliklinik in Basel.

Unfortunately, as has been frequently pointed out, the Stockholm experiments do not include determinations of the oxygen consumption. This deficiency in experimental methods is of special significance in considering the question of carbohydrate ingestion; it likewise renders problematical the calculations and assumptions made by Gigon with regard to the character of the katabolism both during the fasting period and after food.

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[1]Gigon, Skand. Arch. f. Physiol., 1908–09, **21**, p. 351.

[2]Gigon, München. med. Wochenschr., 1911, **58**, p. 1343; and Arch. f. d. ges. Physiol., 1911, **140**, p. 509.

[3]See Gigon, München. med. Wochenschr., 1911, **58**, p. 1343.

Gigon's main contention is that the basal resting metabolism is extraordinarily constant with the same individual over long periods of time. What is even more striking, he claims that the character of the katabolism as apportioned between protein, fat, and carbohydrate is also constant. Most of the experiments in Basel were made during sleep. Gigon concludes that the gas exchange in sleep is perfectly comparable to that "*bei vorsätzlicher Muskelruhe.*" For the Basel average *nüchtern* values he uses for the energy output 22.5 calories per kilogram per 24 hours, for the carbon-dioxide excretion 23.356 grams per hour, and for the oxygen consumption 21.05 grams per hour.

In the protein experiments made in Stockholm, casein was used, hourly doses of 15.56 grams of this food material increasing the carbon-dioxide excretion 4.2 grams per hour (the Stockholm *nüchtern* value of 23.8 grams being used as the basal value). In Basel, with the Jaquet apparatus, the casein was given in 50-gram portions, resulting in an average increase of 5.03 grams carbon dioxide (6.1 per cent) for a period of approximately $3\frac{1}{2}$ hours. Subsequently 100, 150, and indeed 200 grams casein were given; in all instances very considerable increases not only of carbon dioxide but of oxygen were noted. The increment for the carbon-dioxide excretion was 15.5, 22, and 26 per cent of the *nüchtern* value, following 100, 150, and 200 grams of casein respectively. For the oxygen production, 50 grams casein gave 7.4 per cent increase, 100 grams gave 14 per cent, 150 grams gave 22.1 per cent, and 200 grams gave 27.1 per cent increase. Thus when the size of the portion was varied in the ratio of 1 : 2 : 3 : 4, the carbon-dioxide production increased in the ratio of 1 : 4 : 8 : 12 and the oxygen intake increased in the ratio of 1 : 3 : 6 : 9. It should be pointed out that the experiments varied considerably in length and hence a comparison of the various amounts of protein is somewhat uncertain. Gigon contends that the combustion of fat and carbohydrate remains unchanged from the *nüchtern* value when casein is taken.

In the Stockholm sugar experiments 46 grams of sugar per hour were given, this amount producing an increase of 6.1 grams per hour in the carbon-dioxide production. On the assumption that the carbon-dioxide excretion can be taken as an index of the metabolism during the dextrose experiments, Gigon computes a metabolism of about 90 calories per hour or about 20 calories above the normal. In Basel two experiments were made, one with 100 and one with 50 grams of sugar, the 100 grams giving twice as great an increase in the carbon-dioxide production as the 50 grams. In the 2-hour experiments in which 50 grams of dextrose were taken the total heat production was 156 calories, or 6 calories per hour above the *nüchtern* value. In a $4\frac{1}{2}$-hour experiment with 100 grams dextrose an increase of 30 calories over the *nüchtern* value was found, or approximately 6 to 7 calories per hour. In support of his contention that the basal metabolism is unaffected by

the ingestion of food, Gigon points out that in the glucose experiments the course of the nitrogen and the phosphoric-pentoxide excretion is practically uninfluenced by dextrose.

His observations on the ingestion of fat are of special significance, for at least 2 experiments with 50 grams of olive oil showed a distinct depression of the basal metabolism. With 150 grams of oil the metabolism was slightly above the basal value. Contrary to the experience in most laboratories, with a change to a fat diet Gigon noted that there was a decrease in the nitrogen excretion in the urine. This depression of the metabolism is explained by Gigon as being due to the fact that even during fasting there is always a certain amount of *Verdauungsarbeit*, and that the ingestion of oil depresses this, thus affecting the basal value. A careful theoretical discussion is given of the two prevailing views regarding the cause for the increased heat production after food, namely, the *Verdauungsarbeit* theory of Zuntz and the specific dynamic action theory of Rubner.

In discussing the carbohydrate ingestion, Gigon points out that his experiments usually show that there is no increase in the respiratory quotient and that the increase in the gaseous exchange noted must be due to a cause other than an increased combustion of sugar; in most of Gigon's experiments there is little basis for the theory of fat formation from sugar. In discussing the increase following protein disintegration, Gigon concludes that the total protein disintegration does not exceed that of the *nüchtern* value, and that in all probability there is considerable fat formation from protein, together with a small carbohydrate formation.

Finally, following the general contention of Johansson, Gigon maintains that the food is first deposited in the body in different depots, which, in turn, furnish the energy for cellular activity. Since these depots must in large part rely upon fat formation, Gigon points out that there is probably a considerable fat formation and that fat plays a larger rôle in the metabolism than has heretofore been supposed.

Rolly and Undeutsch, 1911–13.—Employing the universal respiration apparatus devised in the Nutrition Laboratory, although in a modified and unnecessarily complicated form, Rolly and his associate Undeutsch made several normal experiments with women in connection with some of their work in pathology. In reporting the results of 1 basal experiment and 3 food experiments, Rolly[1] discusses the respiratory quotient and attempts to explain what he considers to be a very noticeable rise. It is a fundamental error to lay much stress, as Rolly has done, upon a single previously determined basal value. Furthermore, contrary to Rolly's opinion, a *nüchtern* quotient of 0.819 is not high, as experiments with 68 women in the Nutrition Laboratory gave an average respiratory quotient of 0.81. In common with the findings of other experi-

[1]Rolly, Deutsch. Arch. f. klin. Med., 1911–12, **105**, p. 494.

menters, Rolly found that the oxygen consumption was increased by the ingestion of 200 grams of flesh or with protein in other forms.

A far better presentation of this material is given in the dissertation of Undeutsch,[1] who concludes that the vegetable protein preparations cause a greater increase in the total metabolism than the animal protein does. The maximum increase in the metabolism was reached in 1 to 2 hours after the ingestion of the protein. The effect of the protein disappeared at the end of 6 hours.

Amar, 1912.—Employing a Chauveau apparatus with Tissot spirometers, Amar[2] studied the influence of both carbohydrate and protein diets upon metabolism. Two subjects were used. The carbohydrate meal consisted of rice, potato, and bananas, and corresponded to 95.5 grams of carbohydrate. The protein meal consisted of lean meat and eggs; bread and cheese were also added for one of the subjects. The diets corresponded to 80 and 100 grams of protein respectively. In the carbohydrate experiments the oxygen consumption after a meal increased at first, reaching the maximum in 1 hour, then fell off hour by hour. The respiratory quotient increased hour by hour, although it never reached unity. After protein the oxygen consumption immediately increased, this increase reaching its maximum in 2 hours. The carbohydrates caused an average increase in the oxygen consumption of 6 per cent and the protein an average increase of 11 per cent for a period of 3 hours.

Hári and von Pesthy, 1912.—A series of experiments carried out by Hári and von Pesthy,[3] with the usual skill of the Budapest laboratories, was made on three subjects with the Zuntz-Geppert apparatus. The primary object was to study the influence of the temperature of the food on the gas exchange. *Nüchtern* experiments were made first every morning, which were followed by observations after the ingestion of milk. One liter of milk was taken inside of 3 to 4 minutes in one series of 12 experiments at a temperature of 3° to 4° C., and in a second series of 10 experiments at a temperature of 50° to 55° C. The conclusions of the authors bearing on this discussion are that both cold and warm milk increase the oxygen consumption about 13 to 15 per cent for 3 hours after the ingestion of milk. With warm milk this increase ceases shortly after 3 hours, but persists several hours more or less unchanged with cold milk. The authors conclude that the longer effect in the latter case may be due to a slower digestion of cold milk.

Loeffler, 1912.—Loeffler,[4] working under the direction of Gigon in the Poliklinik in Basel, made a study of basal metabolism and likewise

[1]Undeutsch, Experimentelle Gaswechseluntersuchungen bei Morbus basedowii: Grundumsatz und Umsatz nach Aufnahme von animalischem und vegetabilischem Eiweiss. Inaug.-Diss., Leipsic, 1913.

[2]Amar, Journ. de Physiol. et de Path. gén., 1912, **14**, p. 298.

[3]Hári and von Pesthy, Biochem. Zeitschr., 1912, **44**, p. 6.

[4]Loeffler, Arch. f. d. ges. Physiol., 1912, **147**, p. 197.

of the metabolism after the ingestion of 50 grams each of an animal protein (casein) and of a vegetable protein (edestin). For most of his experiments he used the respiration apparatus installed by Gigon, consisting of a spirometer and Müller water-valves. He concludes that the basal metabolism remained constant for more than four years, and that the results obtained with this apparatus agree perfectly with those obtained with the Jaquet and Sondén-Tigerstedt apparatus. Following the ingestion of 50 grams of casein the carbon dioxide increased about 5 grams and the oxygen about 5 grams within a period of 3 to $3\frac{1}{2}$ hours. A similar increase was noted with edestin. Following the lines of reasoning developed by Gigon, the author discusses the question of *Verdauungsarbeit.* He maintains that it exists even in the post-absorptive condition and that therefore this activity is included in the determination of the basal value. He further believes that the increase found by him after the ingestion of protein is due to further changes in the foodstuff after its absorption.

Zuntz and Schirokich, 1912.—In a series of experiments with one subject living on a protein-poor diet, Zuntz and Schirokich[1] studied the metabolism in the *nüchtern* condition as well as after food and found the increment in the heat output in the food experiments to be approximately 15 per cent.

Gigon, 1912.—In an attempt to study the influence of spices and of flavoring materials upon nutrition, Gigon[2] employed the Jaquet respiration apparatus in Basel and made experiments on himself during the night, usually during sleep. Casein in varying amounts was taken with about 1 liter of water. In some of the experiments, 10 grams of salt and 1 gram of pepper were taken with the casein. The increase in the carbon-dioxide production was greater when casein alone was ingested, but the increase was of longer duration when the salt and pepper were added. Gigon notes that the spices had more of an effect on the carbon-dioxide production than they did on the oxygen consumption. This influence was more marked with 50 grams casein than with the larger amounts. In his earlier experiments, in which he specially emphasizes the importance of giving pure food materials in contrast to food materials of mixed composition, such as beefsteak, roasts, etc., Gigon found a more rapid return to the basal value than others have found and he now explains the delayed effect of eating other than pure food materials as being due to the influence of the flavors.

McCrudden and Lusk, 1912–13.—McCrudden and Lusk,[3] in a study of a dwarf 17 years old, with a body-weight of 21 kilograms, found that the basal metabolism in the Cornell calorimeter was increased 6.6 per cent after the ingestion of small quantities of food. This average

[1]Zuntz and Schirokich, Separate from Med. Klinik, 1912, No. 32, 5 pp.
[2]Gigon, Verhandl. deutsch. Kongr. f. inn. Med., XXIX Kongress, 1912.
[3]McCrudden and Lusk, Journ. Biol. Chem., 1912–13, **13**, p. 447.

figure was obtained from the results of 4 experiments in which the metabolism was observed after a meal of carbohydrate and fat, another of lean meat, and two breakfasts, presumably with mixed diet.

Tögel, Brezina, and Durig, 1913.—In connection with a study on the effect of alcohol upon the conservation of carbohydrate combustion, Tögel, Brezina, and Durig[1] report several experiments with both levulose and dextrose. The Zuntz-Geppert technique with all of the Durig refinements was employed. Contrary to their usual custom, they determined the base-line in only one period before each sugar experiment. The subject usually received 100 grams of sugar, but in one experiment 3 doses each of 30 grams of levulose were given at 1-hour intervals. After 100 grams of dextrose the respiratory quotients rose at the end of 2 hours to unity or over. With this subject, who had at that time a high carbohydrate storage, the effect of sugar ingestion was not noticeable after about 4 hours. Of special significance is the fact that even when the subject was in a glycogen-poor condition the typical rise in the curve of the respiratory quotient was not delayed and there was likewise a marked rise in the metabolism, a result somewhat at variance with some of the earlier work. Doses of 100 grams of levulose produced greater increases than the same amounts of dextrose. Although the authors note that the total excess heat produced after giving levulose is greater than that with dextrose, it is worthy of note that the maximum increment in the heat output was essentially the same with both sugars.

Schöpp, 1913.—Schöpp,[2] working with Grafe in the Medical Clinic in Heidelberg, in giving a report of rectal feeding experiments, includes a series of 3 *nüchtern* and 2 food experiments upon himself in which special patented foods were taken *per os*. These experiments, which were about 10 hours in length, were made with the Grafe respiration chamber and with the subject in the post-absorptive condition at the beginning of the experiment. In the food experiments Schöpp found large increases in the heat production of 46 and 33 per cent, respectively. He noted the maximum combustion in the seventh hour, which he is inclined to think was due to toxic peculiarities of the cleavage products of the protein preparations. The conservatism shown in the conclusions drawn from his two experiments may well be copied by all writers on metabolism in discussing fragmentary data.

Grafe, 1913.—Grafe,[3] using his admirable model of the Jaquet apparatus in the Heidelberg clinic for observations on a professional fasting woman, noted that the basal metabolism during fast was 1,180 calories per day or 25 calories per kilogram of body-weight. In the first food experiment after the ingestion of 397 grams carbohydrate and 60 grams

[1]Tögel, Brezina, and Durig, Biochem. Zeitschr., 1913, **50**, p. 296.
[2]Schöpp, Deutsch. Arch. f. klin. Med., 1913, **110**, p. 284.
[3]Grafe, Deutsch. Arch. f. klin. Med., 1913–14, **113**, p. 1.

alcohol, the total calorific value of which was 770 calories greater than the basal value, the heat production fell off slightly in 20½ hours. Grafe points out that this finding agrees with that of Johansson,[1] who observed no increase in the metabolism following the ingestion of carbohydrate by a fasting individual, *i. e.*, an individual with low glycogen storage. In a second respiration experiment, in which the subject took 278 grams of carbohydrate, 120 grams of fat, and 30 grams of alcohol, with a total energy content of about 2,180 calories, the increase in the combustion in 20¾ hours was very small compared with the fasting value, being only 4 per cent. Thus both experiments indicate an extraordinarily small increase in the heat production following the ingestion of non-protein food after fasting.

Howland, 1913.—In studying the addition of nutrose to the ordinary diet in the case of infants, Howland[2] found with the Cornell calorimeter an increase in the heat production per square meter per day of 10 per cent in one case and 26 per cent in another. Although the basal values without food were not obtained, the increment due to the ingestion of the highly nitrogenous nutrose over that with ordinary food is of significance in this connection.

Bergmark, 1914–15.—Bergmark,[3] investigating rectal feeding, reports 4 experiments in which 100 grams and 50 grams of dextrose, respectively, were taken *per os*, the author being the subject. The experiments were made in Johansson's laboratory in Stockholm and with the usual Johansson technique. After 100 grams of dextrose, Bergmark found a rise in the carbon-dioxide production of 14.94 grams in 6 hours and 7.02 grams in the same length of time after 50 grams of dextrose. The character of the katabolism was not shown, as the measurements of the metabolism were based only upon the data for the carbon-dioxide production. The agreement with Johansson's earlier results, however, is proof of the uniformity of technique.

Bergonié, 1915.—Bergonié,[4] without reporting any experimental evidence of his own, calculated the increment in energy output due to the ingestion of three meals a day with a normal individual as being equivalent to 200 calories.

Gephart and Du Bois, 1915.—Du Bois, in carrying out the extended series of researches with the respiration calorimeter in the Russell Sage Institute of Pathology, an apparatus designed especially for the study of pathological cases, decided to include the determination of the basal metabolism of normal men and the effect of food. With Gephart[5] he reports the results of experiments with 7 men with and without food. The basal experiments were made 14 to 18 hours after food. As a

[1]Johansson, Skand. Arch. f. Physiol., 1908, **21,** p. 1.
[2]Howland, Trans. 15th Internat. Cong. Hyg. and Demogr., 1913, **2,** sect. 2, p. 438.
[3]Bergmark, Skand. Arch. f. Physiol., 1914–15, **32,** p. 355.
[4]Bergonié, Rev. Sci. (Paris), 1915, **53,** p. 138.
[5]Gephart and Du Bois, Arch. Intern. Med., 1915, **15,** p. 835.

basal value the authors used 34.7 calories[1] per square meter per hour as the average heat production of fasting normal men between 20 and 50 years of age. After giving 200 grams of dextrose or its equivalent in commercial glucose on 2 days subsequent to the fasting experiments, it was found that this amount caused an average increase of 12.5 per cent in the heat production during the first 3 to 6 hours and that 100 grams caused an average increase of 9 per cent. A casein meal, with 10.5 grams nitrogen, increased the metabolism 12 per cent, and 725 grams of beef, with almost 24 grams of nitrogen, increased it 22 per cent.

Gephart and Du Bois, 1916.—In a continuation of the calorimeter experiments at the Russell Sage Institute of Pathology, Gephart and Du Bois[2] report 3 experiments with one subject, 1 experiment after 79 grams of olive oil, and 2 experiments after 115 grams of commercial glucose. The basal value for these determinations was obtained 2 days after the 3 experiments were completed. The authors state that their subject "1 to 4 hours after 115 grams of commercial glucose (the equivalent of 100 grams dextrose) showed an average metabolism 11 per cent higher than the basal determination two days later." Little increase in the metabolism was noted after the 79 grams of olive oil.

Kopciowski, 1916.—Using the somewhat cumbersome Bürgi apparatus, which was designed primarily for experiments during walking, Kopciowski[3] measured the metabolism on himself in 10-minute experiments before and after food in both the lying and sitting positions; only the carbon-dioxide production was determined. In 13 experiments without food, with the subject in the lying position, he found the average carbon-dioxide production to be 4.557 grams per 10 minutes; after dinner this increased 17 per cent. In 4 experiments without food, with the subject in the sitting position, the carbon-dioxide production was 4.687 grams per 10 minutes; in 17 experiments after breakfast or dinner this was increased to an average of 5.248 grams of carbon dioxide, or an increase of 12 per cent. Without oxygen measurements it is obvious that no corrections can be made for alterations in the character of the katabolism.

Aub and Du Bois, 1917.—A significant series of experiments on dwarfs and legless men with the Russell Sage calorimeter was made by Aub and Du Bois[4] to study the so-called specific dynamic action of protein. The subjects were given a meal of 660 grams of lean beefsteak containing approximately 23 to 25 grams of nitrogen. The investigators laid special emphasis upon the excretion of sulphur. They state that the increase in metabolism following the meat diet was larger for a

[1]Using the Meeh formula. Subsequently the Du Bois linear formula increased this value.
[2]Gephart and Du Bois, Arch. Intern. Med., 1916, **17**, p. 902; Cornell Univ. Med. Bull., 1917, **6**, p. 48.
[3]Kopciowski, Arch. f. d. ges. Physiol., 1916, **163**, p. 247.
[4]Aub and Du Bois, Arch. Intern. Med., 1917, **19**, p. 840.

legless man and for an achondroplastic dwarf with very small arms and legs and normal trunk than for three normal controls of greater weight and greater surface area. They accordingly conclude that the intensity of the specific dynamic action is not proportional to the mass of the musculature, and suggest that it may be due to a greater concentration of amino-acids in the blood flowing to the muscles or to the presence of a liver which, in proportion to the size of the organism, is relatively larger than the normal.

SUMMARY OF PREVIOUS INVESTIGATIONS.

In spite of the wide variations observed in the increase of the metabolism with different foodstuffs, there is a distinct uniformity in the majority of experiments which indicates that the act of taking food results in an increased heat production, carbon-dioxide production, and oxygen consumption. With diets predominating in carbohydrates, the quantitative relationship of these increases is more strikingly noticed in the carbon-dioxide production. With the protein diets, the evidence is more pronounced with the oxygen consumption. With the three typical nutrients we may consider as firmly established: (1) that the ingestion of a diet rich in protein results in a marked increase in the total metabolism both for the oxygen consumption and the carbon-dioxide production, this increase being, in general, roughly proportional to the amount of protein ingested; and (2) that with carbohydrate there is almost invariably a marked increase in the excretion of carbon dioxide, and in many instances, especially with sugars other than dextrose, there is likewise an increase in the oxygen consumption. The exact interpretation of the increases with carbohydrate is not so simple as in the case of protein, for there is undoubtedly a formation of fat from carbohydrate. In respiration experiments in which only the carbon-dioxide production is determined, the interpretation of the increase is obviously very difficult. With a fat diet, the evidence is conflicting and little information is obtainable. Pure fat is rarely given in experiments, but is usually combined with other food materials. In those instances in which it has been included in a mixed diet, a small increase has usually been noted. Two of three experiments made by Gigon with pure olive oil implied a distinct lowering of the basal metabolism. In any event, it is safe to conclude that the influence of the ingestion of fat upon metabolism is very small compared with that of sugar and protein.

Although a considerable portion of the literature is devoted to a discussion of the causes of these variations in the metabolism, the two main theories have been (1) the *Verdauungsarbeit* theory of Zuntz and his scholars, which ascribes the greater proportion of the increased metabolism to the work of digestion, and (2) the specific dynamic

action theory of Rubner. Clear-cut evidence for or against these theories is, in spite of the great mass of experimental data, not readily found. Writers are about evenly divided between the two theories. Those upholding the *Verdauungsarbeit* theory have the distinct advantage of having a definite process to consider. On the other hand, the definition of the specific dynamic action in Rubner's theory, and more particularly the application of the theory, is somewhat obscure and has led to a great deal of confusion. It should be stated, however, that few theories regarding the physiology of digestion have stimulated so much excellent research work as has the specific dynamic action theory.

BASAL METABOLISM.

To study the influence upon metabolism of such a factor as the ingestion of food, the energy requirements of the quiescent body prior to the ingestion of the food must be known, for otherwise the measurement of metabolism after food can have no comparative significance. Thus the whole problem of demonstrating the influence of the ingestion of food upon metabolism depends upon two vitally important processes: (1) the establishment of a suitable base-line, and (2) the accurate measurement of metabolism following the ingestion of food.

While at first sight it might be assumed that the establishment of a base-line is relatively simple, close analysis shows that this is far from being the case. In the first place, there is no normal value for either male or female adults that may be taken, *a priori*, as a base-line for any subsequent measurements. Various attempts have been made to establish more or less crude "standard" values and results have been obtained which give rough indications of the major changes in metabolism due to disease, food, or muscular work. These so-called standard values can not, however, be used for any quantitative study of the influence of a specific factor upon metabolism. Each series of measurements accordingly demands its own basal determination.

In determining basal values, the conditions should preferably be as much as possible like those obtaining during the comparison experiments. Thus, in any research on the effects of bicycle riding, it may be fairly argued that the base-line should be determined not when the subject is lying in deep sleep, but when he is sitting in the ordinary position occupied by a bicycle rider. Again, when the work of horizontal walking is studied, the base-line would not logically be that obtained during deep sleep, but would be a value secured with the subject standing in readiness for walking.

The degree of care necessary in the selection of a base-line is dependent upon the size of the increment in the metabolism due to the superimposed factor. By active muscular work it is perfectly possible for a well-trained athlete to increase his basal metabolism tenfold or more,

the professional bicycle rider studied by us[1] and also the one studied by Benedict and Cathcart[2] showing no difficulty in producing such increases. With values so large as these, it is clear that small differences in the base-line play a comparatively unimportant rôle. Indeed, it has been the custom in the researches on muscular work, published not only from this laboratory but also by investigators elsewhere, to use a basal value determined with the subject lying down but not asleep. While such a practice is theoretically unsound, the increments due to muscular work are so large that in comparisons of metabolism during muscular work and during rest the relatively slight differences between metabolism during sleep and that with the subject standing or sitting quietly or lying down awake may be neglected.

In studies on the influence of food upon metabolism, the increments are much smaller than in studies with muscular work. A glance at the literature (see pages 10 to 46) shows that the maximum effect due to this factor may be to increase metabolism for a short time, possibly 30 or even 40 per cent. When we consider the potential increment of 1,000 or more per cent with muscular work, even this maximum increase in metabolism after food seems comparatively insignificant. Accordingly, in a study on the effect of the ingestion of food, great care should be taken to secure a uniform base-line and a critical examination should be made of those factors liable to influence the determination of the basal metabolism.

The quiescent metabolism of the body may be affected by a number of factors, primarily by muscular activity. We have already seen that severe muscular work increases the metabolism largely, but we find that moderate activity or even the relatively few muscular movements that distinguish between complete rest and ordinary rest also have a definite influence. Furthermore, when the increment in metabolism to be measured is probably small, one has to consider not only minor muscular activity, but even the degree of muscular relaxation. Thus we find Johansson[3] training himself and his co-workers to establish an arbitrarily complete muscular repose. Finally, experimental evidence[4] obtained in the Nutrition Laboratory has shown positively that the quiescent metabolism of a subject asleep differs considerably from that of the same subject awake. In experiments with the subject in a profound sleep there was a noticeable decrease in pulse rate, which was almost invariably accompanied by a decrease in total metabolism. We may expect, therefore, that with the subject in deep sleep there will be a decrease in pulse rate, respiration rate, and muscle tonus, with consequently lower metabolism as compared with values

[1]Benedict and Carpenter, U. S. Dept. Agr., Office Exp. Stas. Bull. 208, 1909.
[2]Benedict and Cathcart, Carnegie Inst. Wash. Pub. No. 187, 1913.
[3]Johansson, Skand. Arch. f. Physiol., 1898, 8, p. 119.
[4]Benedict, Carnegie Inst. Wash. Pub. No. 203, 1915, p. 343.

obtained with the same subject awake and in complete muscular repose. Even though the body be muscularly quiet while lying on a couch or bed and the voluntary muscles be perfectly controlled, the involuntary muscles, such as those of circulation, digestion, and respiration, are active. These involuntary muscles continue their work in deep sleep at a somewhat lower level.

A second factor which definitely affects the base-line is previously ingested food. It has been clearly demonstrated by practically all of the earlier workers that an increased metabolism follows the taking of food, particularly when protein and certain carbohydrates form a part of the diet. If possible, therefore, we must find a point in the digestive cycle at which the metabolism will not be influenced by the previous diet, but which will be prior to the severe drafts upon the body glycogen that have been found in researches at both Wesleyan University and the Nutrition Laboratory during several days of strict fasting. It seems to be the consensus of opinion of nearly all experimenters in this line of research that with normal man, unless the last meal has been excessively rich in protein, active digestion ceases 12 hours after the ingestion of food and the metabolism has then reached essentially the normal level, *i. e.*, the level prior to the taking of food. This has been demonstrated in a number of researches, particularly those of Magnus-Levy.[1] Hence it is now the custom of most experimenters to study the basal metabolism by making experiments 12 or 14 hours after the last meal or, as Benedict and Cathcart have expressed it, with the subject in the "post-absorptive condition,"[2] and to assume that the influence of previously ingested food will in this way be eliminated.[3] The metabolism at this time, however, does not always represent the minimum metabolism, as will be seen in a later discussion.

At this point we may ask: What is the lowest metabolism? If in a normal state of nutrition the voluntary muscles of the body are so perfectly controlled that there is no visible movement, the muscles so relaxed as to diminish the muscle tonus, the pulse rate and the respiration rate depressed to the lowest point, and there is no food in the alimentary tract, and furthermore, if the subject is in deep sleep, we may expect to obtain the minimum metabolism for that particular subject.

The ideal conditions outlined for obtaining such a low metabolism are, as a matter of fact, not readily secured with the majority of subjects. If in studying the influence of a superimposed factor upon metabolism, the measured base-line can be relied upon as uniform, it is not necessary that the lowest metabolism be secured. In experiments which involve relatively slight changes in metabolism, however, the lower the metabolism which can be secured for the base-line, the greater will be the

[1]Magnus-Levy, Arch. f. d. ges. Physiol., 1894, **55,** p. 1; see especially p. 23.
[2]Benedict and Cathcart, Carnegie Inst. Wash. Pub. No. 187, 1913, p. 71.
[3]Benedict and Higgins, Am. Journ. Physiol., 1912, **30,** p. 217.

degree of accuracy in the percentage increase obtained as a result of the superimposed factor.

Even when the basal value has been well established it does not necessarily follow that the metabolism of an individual will remain unchanged for an indefinite length of time, inasmuch as there will be changes in the composition of the body, particularly gains or losses of glycogen and fat; growth, climate, the season of the year, and such factors as temperature environment and various stimuli to the body may likewise have an effect upon metabolism. This question will be considered more at length in the discussion of the various methods for obtaining the basal metabolism.

Of the numerous factors affecting muscle tonus and nerve stimulation, great emaciation and the ravages of disease are distinctly of pathological rather than of physiological significance. In a number of pathological cases, when the metabolism is at a subnormal point through muscular atrophy and similar causes, there may be even less muscle tonus and minor muscular movement than with healthy persons in profound sleep. But these abnormal conditions need not be considered here.

It may be of considerable moment in this connection to note whether or not the increment above the base-line due to the ingestion of a definite amount of food is wholly independent of the absolute value of the base-line. For example, we will assume that the taking of a certain amount of food resulted in an increment of 25 calories during a period of 6 hours when the base-line was determined with the subject in complete muscular repose, in the post-absorptive condition, and lying awake. With the subject asleep, the base-line would unquestionably have been somewhat lower than that obtained with the subject awake. Have we any reason to believe that the increment due to the ingestion of food will be affected by this difference in conditions? Unfortunately our evidence is by no means clear on this point.

The particular problem studied in this publication is the absolute increase in the heat production caused by the ingestion of food. Aside from disease, the two principal factors which contribute to the depression of the base-line are sleep and fasting. It is conceivable that with a low base-line, such as would be found in deep sleep or during fasting, a greater increment would be obtained with a definite amount of food than with a higher base-line. On the other hand, it is possible that during sleep, and especially with a condition of under-nutrition resulting from fasting, the cells may be less susceptible to stimuli. In such a case the increment in the metabolism would obviously be less than when the subject is awake and in a normal state of nutrition.

Experiments primarily measuring the output of heat resulting from a definite amount of muscular work have shown that if the basal value

is increased for any reason, either by previous alcoholic excess[1] or by preceding diet,[2] the increment in the heat production per unit of work is not measurably altered. This is in full conformity with the contention of Johansson and Koraen[3] to the effect that the thermal processes accompanying food ingestion and those accompanying muscular work are entirely distinct from each other. The only striking illustrations in the literature of the opposite of this hypothesis are the observations of Durig,[4] whose technique it is very difficult to criticize adversely; his results should therefore be considered as absolutely established facts. In Durig's Vienna experiments the basal metabolism was approximately 1 calorie per minute, while in the Monte Rosa experiments it was 1.26 calories per minute. The increment due to the ingestion of sugar was 0.268 and 0.306 calorie per minute in Vienna; on Monte Rosa with the same amount of sugar it was 0.206 and 0.115 calorie per minute. It would seem, therefore, as if with the higher base-line the sugar had a less stimulating effect.

For all practical purposes, however, we need not at present consider these special conditions, but may assume that if the base-line is determined under conditions of complete muscular repose, the increment measured will represent the true effect of the ingestion of food upon the metabolism irrespective of whether the subject is asleep or awake. The possible variations in the magnitude of this effect, due to the subject being either asleep or awake, call for experimental evidence, and as yet we have none at hand.

BASAL VALUES USED IN THIS RESEARCH.

As the researches recorded in this publication have extended over a considerable period of time, namely, from 1904 to 1915, and this period has witnessed a rapid development of technique in all forms of metabolism measurements, it is not surprising that we find variations in the interpretation of the significance and importance of the base-line and in the method of studying the metabolism following food ingestion.

The experiments reported in this publication may be divided into three groups: First, those 24 hours in length; second, those approximately 8 hours in length; and third, those in which the individual periods were of short duration. The variations in the length of the period naturally resulted in a variation in the method of obtaining the basal metabolism. In the 24-hour experiments the basal metabolism was determined for each individual for one or more days and compared with 24-hour values determined on other days for the metabolism after food ingestion. In the earlier 8-hour experiments, the basal metab-

[1] Benedict and Murschhauser, Carnegie Inst. Wash. Pub. No. 231, 1915, p. 78.
[2] *Ibid.*, pp. 80 and 93.
[3] Johansson and Koraen, Skand. Arch. f. Physiol., 1902, **13**, p. 251.
[4] Durig, Denkschr. d. Wiener Akad. d. Wiss., 1909, **86**, p. 116.

olism and the metabolism after food were determined on separate days, but later in the research the food was frequently given after several hours of fasting and the measurements continued for the remainder of the 8 hours. Thus, in these later experiments, the basal metabolism and the metabolism after food were determined on the same day. In the short-period experiments the basal metabolism was measured on the same plan as that used in most of the later 8-hour experiments, *i. e.*, in several periods preceding the ingestion of food.

Both the 24-hour experiments and the 8-hour experiments were carried out with respiration calorimeters, by means of which not only the carbon-dioxide production and the oxygen consumption could be measured, but also the heat production. The short-period experiments, in which the individual periods were approximately 15 minutes long, were made with respiration apparatus which gave measurements of only the carbon-dioxide production and the oxygen consumption. The heat production was calculated by the indirect method.

The main object in all these experiments was essentially the same, namely, to secure a constant base-line upon which could be superimposed the factor of the ingestion of food. With the 24-hour base-line it was necessary to assume that the metabolism was constant from day to day; with the earlier 8-hour base-line, that it was constant on different days; and in the experiments in which the base-line was determined on the same day as the metabolism after food (the later 8-hour experiments and the short-period experiments), that the metabolism was constant from hour to hour throughout the day. From a consideration of these plans of experimenting it is easily seen that the probability of constancy in muscular activity is not the same for all types of experiments. The advantages and disadvantages of each method may therefore be discussed more in detail in connection with the results obtained in the determinations of the basal metabolism.

EXPERIMENTS OF 24 HOURS' DURATION.

The earliest experiments included in this study, which were made with the respiration calorimeter at Wesleyan University, Middletown, Connecticut, used the 24-hour day as a unit. This was in accordance with the usage of the Munich school of Carl Voit, in which Professor W. O. Atwater of Wesleyan University obtained his introduction to metabolism experiments; practically all of the researches with the large calorimeter at Wesleyan University which have been published since 1897 have been based upon the 24-hour day.

A study of the metabolism during inanition was first attempted with the idea of using the results of the fasting experiments as a base-line in a supplementary study of the effect upon metabolism of the ingestion of food. This was done in the belief that a knowledge of the

gaseous metabolism and energy transformations during prolonged fasting would be of fundamental importance, and furthermore, that after such a fast ideal conditions would be present for studying the superimposed factor of the ingestion of food.

These fasting experiments varied in length from 1 to 7 days. To obtain like activity in the basal periods and in those following food, it was the custom to watch the subject continuously during the fasting period and to record each movement. A program was then prepared, duplicating in every detail the movements of the fasting period, and in the comparison food experiment the subject was requested to follow this program faithfully. It was assumed that the narrow confines of the chamber and the routine program would so restrict the muscular activity of the subject on the food days that the degree of intensity would approximate that of the fast days.

The experiments as planned included one or more periods of observation when the subject was lying, presumably asleep, inside of the respiration chamber; it was believed that these periods would give ample opportunity for studying the most quiet metabolism of the fasting individual. At that time evidence was not secured regarding the constancy in the degree of muscular repose during these sleeping periods, aside from the reports of the subjects themselves as to their condition during the night. It was almost invariably reported that the subject slept moderately well. Certainly the men did not at any time leave the couch and the muscular activity, if there were such, did not cause a sufficient heat disturbance to attract the attention of the physical observer.

The influence of the ingestion of food was determined by noting the basal metabolism in 24 hours without food and comparing it with the metabolism during a 24-hour period in which a particular diet was ingested, the increment in the metabolism showing the increase due to the ingestion of the food.

CRITIQUE OF 24-HOUR METHOD.

This method of determining the metabolism in 24-hour periods has been regularly employed by many investigators. It was used by Johansson and his associates[1] in the Stockholm laboratory in considering the effects of food following a 5-day fast. In Johansson's experiments the food ingestion immediately followed or immediately preceded the fasting days. In the experiment of 5 consecutive days reported by Rubner,[2] on the first day there was hunger and rest, on the second protein diet and rest, on the third protein diet and work, on the fourth sugar diet and rest, and on the fifth sugar diet and work.

[1]Johansson, Landergren, Sondén, and Tigerstedt, Skand. Arch. f. Physiol., 1897, **7**, p. 29.
[2]Rubner, Sitzber. K. Preuss. Akad. Wiss., 1910, p. 316.

Theoretically the measurement of the basal value during a 24-hour fast, to be immediately followed by a day in which the prescribed food intake is given, is an ideal method for studying the influence of the ingestion of food, inasmuch as it includes the activities of a complete normal day. The subject is thus awake during the major part of the 24-hour period and asleep the normal time, the movements being restricted to those possible inside a respiration chamber, such as dressing and undressing, drinking water, telephoning, urinating, and similar activities. By means of the program prepared for the subject, this daily cycle of normal activity could be approximately duplicated in comparison experiments without difficulty. In some respects the longer periods are pleasanter for the subject, as more freedom is allowable in the routine and strict muscular repose is not necessary.

As the total amounts of carbon dioxide given off and oxygen consumed are relatively large in a 24-hour experiment, the experimental errors are practically eliminated; the chemical and physical measurements thus have a greater degree of manipulative accuracy than is the case in short periods.

Furthermore, the continuance of food experiments for 24 hours insures a complete measurement of the effect of food, especially with certain diets, for undoubtedly the influence lasts at times longer than the 12 hours usually assumed to establish post-absorptive conditions. Finally, the long-period experiment allows the ingestion of food at the regular times of the day and in the regular amounts, thus permitting a summation effect and the obtaining of information as to the influence of the diet upon the basal metabolism for the whole day.

On the other hand, the 24-hour period can not give a minimum metabolism value for the subject, since it necessarily includes so much extraneous muscular activity. Although the method used to secure comparable activity in the experiments was as satisfactory as was then possible, it could give only an approximate control, with no assurance of perfect uniformity. Ocular evidence of the activity is at best more or less unreliable, as observers vary widely in their estimates of the quantitative relationships of various minor muscular movements.

The 24-hour type of experiment has yet another disadvantage, for although the deprivation of food for 24 hours is by no means so great a hardship as would ordinarily be supposed, yet the enforced abstinence from food for this length of time is not borne so cheerfully by the majority of individuals as is the short-period fasting.

Again, the 24-hour period gives no information as to the time relations or the maximum effect following the ingestion of food. We are thus unable to tell from the results whether the increase extends over a long period or whether there is a sharp rise and fall in metabolism, *i. e.*, a "peak" effect. Nor does it take into consideration the remote possibility of a compensation—that is, a subsequent lowering of metab-

olism. The evidence as a rule indicates an increment in metabolism, but certain experiments, as we have seen in the summary of the literature on this subject (see page 40), have at least suggested a depression of the basal metabolism.

Furthermore, with the 24-hour period it is practically impossible to detect slight increases, which may actually occur but be lost in the daily quota. These increases could be demonstrated if the maximum effect could be obtained by means of measurements in short periods immediately following the ingestion of food. In a study on the influence of food upon metabolism it would therefore be expected that the 24-hour type of experiment could be satisfactorily used only when studying classes of foods which produce a considerable increment in metabolism rather than for securing evidence regarding foods which cause but a slight increase in metabolism.

DISCUSSION OF RESULTS OF FASTING AND FOOD EXPERIMENTS ON THE 24-HOUR BASIS.

In view of the results obtained in the fasting studies carried out at Wesleyan University and later in the Nutrition Laboratory, the selection of a suitable basal value to be used for the 24-hour food experiments has been a subject of much consideration. As will be shown later, in our discussion of the experiments and in our conclusions as to the use of this type of experiment, the length of the fast influences the increment in the metabolism due to the ingestion of food. In discussing the basal metabolism in this special group of 24-hour experiments, therefore, it has seemed desirable to give the detailed results obtained after the taking of food, presenting only those fasting values which have been selected for the base-line. The data for the food experiments, when significant, will later be included in abstract in several tabular presentations of final results and in the discussion of special food topics. They are presented here primarily as material for a critical study of the general principle of the use of 24-hour periods. In giving the data for these experiments, the fuel value of the diet, *i. e.*, the heat of combustion less the unoxidized portion of the protein excreted in the urine, has been used in all cases. For the method employed in calculating these values, see page 334.

The first series of experiments on the 24-hour basis is that for A. L. L., December 16 to 23, 1904.[1] In this series 4 fasting days preceded the ingestion of milk and plasmon. In table 7 the average of the first 2 days is used as a base-line, these values being the best available for comparison, as will be shown later (see page 70). The average excretion of nitrogen for the first 2 days of fast was 12.18 grams, the carbon-dioxide production 649 grams, the oxygen consumption 615 grams, and

[1]For the detailed results of this series see Benedict, Carnegie Inst. Wash. Pub. No. 77, 1907, experiments Nos. 69 and 70.

the heat production 2,057 calories. An examination of the values for the fourth day of fast, December 19 to 20, shows that they are somewhat lower than the basal values obtained from an average of the first 2 days. On all of the 3 food days there was a gradual increase in the carbon-dioxide excretion, oxygen consumption, and heat production as a result of the ingestion of the milk and plasmon, the largest amount being on the last day. Thus, on the 3 days with food there were successive increases of 4, 37, and 128 grams in the carbon-dioxide production, 7, 56, and 118 grams in the oxygen consumption, and 47, 166, and 400 calories in the heat production.

TABLE 7.—*A. L. L., December 16–23, 1904.* (24-hour periods, 7 a. m. to 7 a. m.)

Milk and plasmon:[1]
Amount, 1,621 grams; nitrogen, 8.57 grams; total energy, 2,577 calories.
Fuel value, 2,502 calories; from protein, 9 per cent; from fat, 79 per cent; from carbohydrates, 12 per cent.

Experimental day.	Date.	Nitrogen in urine.	Carbon dioxide.		Oxygen.		Heat.	
			Total.	Increase.	Total.	Increase.	Total.	Increase.
Fast:	1904.	*grams.*	*grams.*	*grams.*	*grams.*	*grams.*	*cals.*	*cals.*
First...	Dec. 16–17..	10.09	632	...	584	...	1,951	...
Second.	Dec. 17–18..	14.26	666	...	646	...	2,163	...
Third..	Dec. 18–19..	15.04	641	...	619	...	2,035	...
Fourth.	Dec. 19–20..	12.97	613	...	601	...	1,958	...
	Av. first 2 days.....	12.18	649	...	615	...	2,057	...
Food:								
First...	Dec. 20–21..	13.04	653	4	622	7	2,104	47
Second.	Dec. 21–22..	9.84	686	37	671	56	2,223	166
Third..	Dec. 22–23..	10.15	777	128	733	118	2,457	400

[1]Expressed as average per day, since the amounts and nutrients were essentially the same each day.

With this particular experiment, in which an increment was noted on all 3 days with food, the discussion of the results is comparatively simple. Judging by this experiment alone, it is clear that the ingestion of food increased the metabolism over that of the fourth day of fasting, thus bringing the values for the first food day positively above the average for the first 2 days of fasting; there was also a cumulative effect, for although exactly the same amount of food was given each day and there was apparently the same amount of muscular activity, the metabolism distinctly increased each day. This increase amounted on the first day to but 2 per cent of the fuel value of the intake, on the second day to 7 per cent, and on the third day to 16 per cent. As only a small amount of plasmon was taken and the milk used was a modified milk and contained considerable fat, the actual

amount of nitrogen ingested was not large; hence the increment due to the stimulating action of protein could not be expected to be very great. In addition, it should be pointed out that 79 per cent of the energy came from milk fat. Obviously if the last day of fasting were taken as the base-line, all of the increments would be materially larger.

The next series of experiments, that with S. A. B., January 7 to 12, 1905, included a 4-day fasting experiment, followed by a food experiment of only one day, as the subject was unable to continue the diet longer.[1] The results of this latter experiment are given in table 8. The food consisted of the somewhat unusual combination of a modified milk and orange juice, a diet insisted upon by the subject as a sup-

TABLE 8.—*S. A. B., January 8–12, 1905.* (24-hour periods, 7 a. m. to 7 a. m.)

Milk and orange juice:
Amount, 1,359 grams; nitrogen, 6.24 grams; total energy, 1,752 calories.
Fuel value, 1,698 calories; from protein, 9 per cent; from fat, 73 per cent; from carbohydrates, 18 per cent.

Experimental day.	Date.	Nitrogen in urine.	Carbon dioxide.	Oxygen.	Heat.
Fast:	1905.	*grams.*	*grams.*	*grams.*	*cals.*
Second[1]	Jan. 8– 9	11.04	570	554	1,844
Third	Jan. 9–10	13.10	554	538	1,746
Fourth	Jan. 10–11	10.74	508	493	1,606
	Second day.	11.04	570	554	1,844
Food:					
First	Jan. 11–12	10.66	525	517	1,677

[1]First day not included because of work done on bicycle ergometer.

posedly advantageous method of breaking a moderately long fast. As on the first day of fasting there was more muscular activity than usual, the values obtained on that day are not suitable for a base-line. The food values are therefore compared with those for the second day of the fast. On comparing the fasting and food values, we find that this experiment differs from that preceding in that here the digestive activity produced no increment in the metabolism, the values for the food day being lower than those for the second day of fast. On the other hand, when the fourth day is used as a base-line, there appears to be an increase in the metabolism after the food. It should be noted in this connection that the amount of energy in the diet from both protein and carbohydrates was small, the total fuel value of the food being only 1,698 calories. The only deduction which can be made from this experiment is that after 4 days of fast, the ingestion of 1,359 grams of food of the composition noted was not sufficient to raise the

[1]For the detailed results of this series, see Benedict, Carnegie Inst. Wash. Pub. No. 77, 1907, experiments Nos. 71 and 72.

metabolism above the level of the second day of fast, although the values were somewhat increased by the food over those obtained for all the factors during the fourth fasting day, which immediately preceded the taking of the milk and orange juice.

Somewhat similar conditions exist in the next series of experiments with the same subject S. A. B., January 28 to February 5, 1905.[1] This consisted of a 5-day fasting experiment, followed by a 3-day food experiment. (See table 9.) A mixed diet was used, consisting of modified milk, orange juice, a small quantity of apple, and a few graham crackers. This diet was somewhat above maintenance in energy, but small in nitrogen content. After 5 days of continuous fasting, the effect of the amount of food taken was not sufficient to bring the metab-

TABLE 9.—*S. A. B., January 28–February 5, 1905.* (24-hour periods, 7 a. m. to 7 a. m.)

Mixed diet (per day):
Amount, 1,671 grams; nitrogen, 6.37 grams; total energy, 2,133 calories.
Fuel value, 2,078 calories; from protein, 8 per cent; from fat, 65 per cent; from carbohydrates, 27 per cent.

Experimental day.	Date.	Nitrogen in urine.	Carbon dioxide.	Oxygen.	Heat.
Fast:	1905.	*grams.*	*grams.*	*grams.*	*cals.*
First.....	Jan. 28–29.....	10.29	609	544	1,866
Second.....	Jan. 29–30.....	11.97	560	548	1,791
Third.....	Jan. 30–31.....	11.54	542	533	1,739
Fourth.....	Jan. 31–Feb. 1..	10.39	515	503	1,663
Fifth.....	Feb. 1–2.....	9.98	482	486	1,548
	Av. first two days.	11.13	585	546	1,829
Food:					
First.....	Feb. 2–3.....	10.74	529	512	1,691
Second.....	Feb. 3–4.....	8.25	530	489	1,585
Third.....	Feb. 4–5.....	6.78	527	495	1,607

olism up to the values obtained on the first 2 days of the fast. Nor did the continued ingestion of the food materially alter the total metabolism in any way. The results of this experiment are in striking contrast to those obtained for A. L. L., on December 16 to 23, 1904 (see table 7, page 56), in which there was a continued increase in the values obtained on the food days. The fuel value of the food used for the experiment with A. L. L. was, however, about 25 per cent higher than that given to S. A. B. If the results for the fifth day of the fast are used as a base-line in this experiment with S. A. B., the metabolism on the food days will show a positive increment for all 3 days, although the increment on the second day is very small for both the oxygen consumption and the heat production. Indeed, the food experiment in this series seems to indicate simply a maintenance of the fasting

[1] For the detailed results of this experiment, see Benedict, Carnegie Inst. Wash. Pub. No. 77, 1907, experiments Nos. 73 and 74.

value originally established at the end of the fifth day of fasting, for it is apparent that although the body requirement was only about 1,600 calories, the ingestion of food having a fuel value of about 2,000 calories was not sufficient to raise the metabolism to the initial level of the first two fasting days, *i. e.*, 1,800 calories. In this, as in all other experiments, strict attention was paid to the necessity of securing comparable conditions of muscular activity. Such variations as were unquestionably present have been carefully discussed in detail in a previous publication.[1] The data there given show that the energy of the estimated muscular activity was extraordinarily constant throughout the 5 days of fasting and the 3 days with food; the difference can not therefore be explained by differences in muscular activity.

Still another series of experiments was made with this subject March 4 to 14, 1905, in which the fasting experiment continued for 7 days and the food experiment 3 days.[2] The diet in the food experiment consisted of milk, gluten crackers, an apple, orange juice, and a small quantity of a breakfast food. As shown in table 10, the average value for the heat production for the first 2 days was 1,767 calories.

TABLE 10.—*S. A. B., March 4–14, 1905.* (24-hour periods, 7 a. m. to 7 a. m.)

Mixed diet (per day):
Amount, 1,274 grams; nitrogen, 6.45 grams; total energy, 1,841 calories.
Fuel value, 1,788 calories; from protein, 9 per cent; from fat, 37 per cent; from carbohydrates, 54 per cent.

Experimental day.	Date.	Nitrogen in urine.	Carbon dioxide.	Oxygen.	Heat.
Fast:	1905.	*grams.*	*grams.*	*grams.*	*cals.*
First.....	Mar. 4– 5.....	12.24	570	534	1,765
Second.....	Mar. 5– 6.....	12.45	551	534	1,768
Third.....	Mar. 6– 7.....	13.02	545	536	1,797
Fourth.....	Mar. 7– 8.....	11.63	534	520	1,775
Fifth.....	Mar. 8– 9.....	10.87	496	491	1,649
Sixth.....	Mar. 9–10.....	10.74	477	466	1,553
Seventh....	Mar. 10–11.....	10.13	476	466	1,568
	Av. first two days.	12.35	561	534	1,767
Food:					
First.....	Mar. 11–12.....	10.17	551	527	1,767
Second.....	Mar. 12–13.....	7.15	560	500	1,728
Third.....	Mar. 13–14.....	7.82	608	507	1,754

After the ingestion of the mixed diet, which had a fuel value of 1,788 calories, the metabolism returned to the level of the first 2 days, but was not raised above it. It was, however, about 200 calories higher than the metabolism on the seventh day of the fast. Thereafter the metabolism remained essentially constant, the progressive increment

[1]Benedict, Carnegie Inst. Wash. Pub. No. 77, 1907, p. 486, table 234.
[2]For the detailed results of this experiment, see Benedict, Carnegie Inst. Wash. Pub. No. 77, 1907, experiments Nos. 75 and 76.

noted with A. L. L. being absent. We have here, therefore, the singular fact that this diet was sufficient to raise the metabolism after 7 days of fast to the initial level of the first 2 days of the fast, while in the experiment with the same subject on February 2 to 5, a diet containing about 300 more calories was not able to produce this effect. An analysis of the character of the diet shows that the percentage of protein was essentially the same in both instances, but that the carbohydrate contained double the amount of energy in this experiment, with a corresponding reduction in the proportion from fat. It is not impossible, therefore, that the action of the carbohydrate accounts for the apparent discrepancy between the two sets of results. Since even in this experiment there was no evidence of an increment if the first 2 days of fasting are taken as a base-line, we can consider the stimulating effect of the food as simply compensating for the decrease in the metabolism produced by the specific effect of the fasting. It is only when this depressing influence of fasting has been completely overcome that the stimulating action of the food is apparent. In the plan of experimentation thus far used it is clear that the problem is distinctly complicated by the conditions involving the depressant effect of a prolonged fast and by the attempt to superimpose the stimulating effect of the ingested food.

As a result of the somewhat unsatisfactory experience with fairly long preliminary fasts, the experimental plan was altered so as to include fasts of only 2 days' duration in an attempt to minimize the depressing influence of the fasting and yet to secure a suitable base-line for determining the influence of food. Several experiments were made on this plan. The fasting data have already been published for most of these experiments,[1] but the results are repeated in abstract here.

The first series of experiments on this later plan was made with H. R. D., December 5 to 8, 1905, there being 2 days of fasting followed by 1 day with a mixed diet. The metabolism on the 2 days of fasting was remarkably constant, with an average heat production of 1,910 calories. On the food day the heat production increased practically 190 calories after the ingestion of food having a fuel value of 2,086 calories. In this instance, therefore, the fasting did not so depress the metabolism as to make it unresponsive to the stimulus of the ingested food. It should be noted that the percentage of energy from protein was somewhat larger than in the experiments thus far considered and the proportion from carbohydrates was likewise large. The details are given in table 11.

A series of experiments was also made with N. M. P., December 9 to 12, 1905, in which a mixed diet was given. (See table 12.) The fasting experiments do not show so close an agreement as was found

[1]Benedict, Carnegie Inst. Wash. Pub. No. 77, 1907, p. 222.

in the preceding series with H. R. D., the individual values being 2,109 and 2,305 calories for the heat production, with an average of 2,207 calories. The food was taken at the usual meal times and the quantities were so adjusted that a large amount could be eaten by the subject. The metabolism was considerably increased by the food, the increment in the carbon-dioxide production being 180 grams, in the oxygen

TABLE 11.—*H. R. D., December 5–8, 1905.* (24-hour periods, 7 a. m. to 7 a. m.)

Mixed diet:[1]

Amount, 2,010 grams; nitrogen, 12.66 grams; total energy, 2,197 calories.
Fuel value: Total, 2,086 calories; from protein, 16 per cent; from fat, 35 per cent; from carbohydrates, 49 per cent.

Date.	Nitrogen in urine.	Carbon dioxide.		Oxygen.		Heat.	
		Total.	Increase.	Total.	Increase.	Total.	Increase.
1905.							
Without food:	*grams.*	*grams.*	*grams.*	*grams.*	*grams.*	*cals.*	*cals.*
Dec. 5–6....	13.25	607	..	585	..	1,914	...
Dec. 6–7....	13.53	579	..	554	..	1,907	...
Average..	13.39	593	..	570	..	1,910	...
With food:							
Dec. 7–8....	11.97	666	73	626	56	2,099	189

[1]The food was eaten mostly in three portions, at 9 a. m., 2 p. m., and 6 p. m.

TABLE 12.—*N. M. P., December 9–12, 1905.* (24-hour periods, 7 a. m. to 7 a. m.)

Mixed diet:[1]

Amount, 3,098 grams; nitrogen, 23.54 grams; total energy, 4,690 calories.
Fuel value: Total, 4,486 calories; from protein, 14 per cent; from fat, 30 per cent; from carbohydrates, 56 per cent.

Date.	Nitrogen in urine.	Carbon dioxide.		Oxygen.		Heat.	
		Total.	Increase.	Total.	Increase.	Total.	Increase.
1905.							
Without food:	*grams.*	*grams.*	*grams.*	*grams.*	*grams.*	*cals.*	*cals.*
Dec. 9–10..	11.37	697	...	628	...	2,109	...
Dec. 10–11..	11.35	719	...	676	...	2,305	...
Average..	11.36	708	...	652	...	2,207	...
With food:							
Dec. 11–12..	17.64	888	180	756	104	2,586	379

[1]The food was eaten in four portions, at 8 a. m., 1 p. m., 6 p. m., and 10^h30^m p. m.

consumption 104 grams, and in the heat production 379 calories. That this increase was coincidental with the ingestion of a large amount of nitrogen and with a considerable part of the fuel value coming from carbohydrate is not surprising. The fuel value of the total diet was practically twice the daily requirements in the fasting period. The noticeable increase in the nitrogen excretion on the day with food is explained by the high nitrogen content of the diet.

A series of experiments was carried out with D. W., January 10 to 14, 1906, which was similar in plan to those with H. R. D. and N. M. P., except that the food experiment was continued for a second day. The data are shown in table 13. The two fasting days gave results which agree fairly well with each other. After the ingestion of a

TABLE 13.—*D. W., January 10–14, 1906.* (24-hour periods, 7 a. m. to 7 a. m.)
Mixed diet (per day):[1]
Amount, 616 grams; nitrogen, 5.11 grams; total energy, 988 calories.
Fuel value: Total, 943 calories; from protein, 14 per cent; from fat, 20 per cent; from carbohydrates, 66 per cent.

Date.	Nitrogen in urine.	Carbon dioxide.		Oxygen.		Heat.	
		Total.	Increase.	Total.	Increase.	Total.	Increase.
1906.							
Without food:	*grams.*	*grams.*	*grams.*	*grams.*	*grams.*	*cals.*	*cals.*
Jan. 10–11..	9.99	722	..	645	..	2,150	...
Jan. 11–12..	14.46	706	..	681	..	2,254	...
Average..	12.23	714	..	663	..	2,202	...
With food;							
Jan. 12–13..	15.66	721	7	672	9	2,233	31
Jan. 13–14..	12.03	775	61	723	60	2,386	184

[1]Breakfast cereal and milk; eaten in three portions each day.

mixed diet with a fuel value of only 943 calories, the metabolism on the first day after fasting was very slightly increased—hardly more, indeed, than would be expected as the limit of error. On the second day, with the same diet, the metabolism showed a very perceptible increase of 184 calories, a distinct indication of the influence of the ingestion of food. The results of this experiment are not unlike those found in the food experiments with A. L. L.—the first 24-hour experiment discussed—in which there was a continually increasing metabolism on the days following fasting. In the former case, however, the fuel value was sufficiently large to supply the daily requirements, while in this experiment the fuel value of the food was less than half that of the body needs. Inasmuch as this man was subsisting on an insufficient diet, the experiment with D. W. can hardly be termed an experiment with food, but is more properly classified as an experiment with partial inanition. In this experiment, as in the others, every attempt was made to secure uniformity in the activity. An examination of the records of the physical observer for the second day and of the figures for the total heat production show that the excess heat on this day was given off during the night between 11 p. m. January 12 and 7 a. m. January 13. This heat output can not, therefore, be considered as a digestive function, for the subject reported a very wakeful night; the records also show that he telephoned twice, although on the first day he had not done this. It is thus probable that the increment on this

second day may in large part be accounted for by the difference in the muscular activity of the two days, especially during the wakeful night, and hence the results are not comparable.

All of the food experiments thus far considered were made with a mixed diet. As it seemed desirable to study specific food substances, an experiment was made with one subject, A. H. M., in which an exclusively fat diet was given. The basal values for comparison were drawn from a 2-day fasting experiment with the same subject, carried out December 3 to 5, 1906, which was a duplicate of an experiment made on November 21 to 23, 1905. This repetition was due to the fact that, in a complete survey of the figures obtained with the subjects of the short fasts at Wesleyan University, it was found that A. H. M. gave indications of having stored glycogen during the November experiment, and it was thus desirable to find if this subject consistently gave abnormal values for katabolized glycogen. The results of the first fasting experiment have been given in full in an earlier publication,[1] but the second experiment was made over a year afterward and too late to include in that report. As the results for the fasting experiment December 3 to 5, 1906, have not heretofore been published, the data are given in considerable detail in this publication.[2]

The routine of this later experiment was but little modified from that of the experiment of November 21 to 23, the records of the body activity being substantially the same as in the earlier experiment. The body-weight without clothing at 7 o'clock each morning was 65.8 kilograms, 64.6 kilograms, and 63.4 kilograms for the 3 days, respectively, indicating the usual somewhat rapid loss in weight during the first few days of fasting. The records of the pulse rate, respiration rate, strength tests, and body-temperature did not vary appreciably from the values obtained in the earlier experiments with this subject and with others. On the first fasting day the subject drank 114.7 grams of water and the weight of urine was 526.8 grams; on the second day he drank 186.3 grams of water and the weight of urine was 569.1 grams. The carbon-dioxide production, oxygen consumption, and water vaporization were determined as usual in 2-hour periods throughout the entire experiment; the nitrogen in the urine was also determined. From these values the complete metabolism was obtained. The data for the total carbon-dioxide production, oxygen consumption, and heat production, are given in table 14 (see p. 64); those obtained from the analysis of the urine are given in table 15. The subdivision of the income and outgo in terms of elements is shown in table 16, while the elements and materials katabolized, which have been computed in accordance with the usual method,[3] are recorded in table 17.

[1]Benedict, Carnegie Inst. Wash. Pub. No. 77, 1907, p. 222 *et seq.*
[2]See, also, statistics for the fasting days Dec. 3 to 5, 1906, on p. 251.
[3]Benedict, Carnegie Inst. Wash. Pub. No. 77, 1907, p. 37.

A comparison of the energy as computed from body material katabolized with the heat production as measured is given in table 18.

TABLE 14.—*A. H. M., December 3–6, 1906.* (24-hour periods, 7 a. m. to 7 a. m.)

Mayonnaise, lettuce, and lemon:
Amount, 213 grams; nitrogen, 0.37 gram; energy, 1,112 calories.
Fuel value: Total, 1,109 calories; from protein, 1 per cent; from fat, 98 per cent; from carbohydrates, 1 per cent.

Date.	Nitrogen in urine.	Carbon dioxide.		Oxygen.		Heat.	
		Total.	Increase.	Total.	Increase.	Total.	Increase.
1906.							
Without food:	*grams.*	*grams.*	*grams.*	*grams.*	*grams.*	*cals.*	*cals.*
Dec. 3–4....	9.15	605	..	545	..	1,830	..
Dec. 4–5....	13.07	595	..	565	..	1,947	..
Average..	11.11	600	..	555	..	1,889	..
With food:[1]							
Dec. 5–6....	13.05	596	−4	565	10	1,918	29

[1]Subject finished eating about 2¾ hours after beginning of period.

TABLE 15.—*Weight, composition, and heat of combustion of urine in fasting experiment with A. H. M., December 3–5, 1906.*

	Preliminary, Dec. 2–3, 1906.	Dec. 3–4, 1906.	Dec. 4–5, 1906.
(*a*) Total weight.....grams..	1,302.2	526.8	569.1
(*b*) Water.....grams..	.....	.....	525.58
(*c*) Solids, *a*−*b*.....grams..	.....	.....	43.52
(*d*) Nitrogen.....grams..	17.51	9.15	13.07
(*e*) Creatinine (preformed).....grams..	.....	1.191	1.366
(*f*) Total creatinine.....grams..	.....	1.334	1.386
(*g*) Creatine[1] (preformed), *f*−*e*..grams..	.....	.143	.020
(*h*) Chlorine.....grams..	9.392	2.477	1.555
(*i*) Sodium chloride.....grams..	15.498	4.088	2.565
(*j*) Heat of combustion.....calories..	.....	76	101
(*k*) Specific gravity.....	1.0271	1.0247	1.0287

[1]In terms of creatinine.

The carbon-dioxide production and oxygen consumption for the two fasting days agree very closely, but there is a difference of approximately 120 calories in the heat production. The respiratory quotient for the first day of fast was 0.81 and for the second 0.77. These values are somewhat higher than the average values found for all the subjects of short fasts recorded in the earlier report,[1] which were for the first day of fast 0.79 and for the second 0.75, although in at least two instances in these short fasts a value was found as high as 0.77 on the second day.

[1]Benedict, Carnegie Inst. Wash. Pub. No. 77, 1907, p. 451, table 225.

TABLE 16.—*Elements katabolized in body in fasting experiment with A. H. M., December 3–5, 1906.*

	(*a*) Total weight.	(*b*) Nitrogen.	(*c*) Carbon.	(*d*) Hydrogen.	(*e*) Oxygen.
First day, Dec. 3–4, 1906:	*grams.*	*grams.*	*grams.*	*grams.*	*grams.*
Income: Oxygen from air	544.8	.....	.....	.....	544.8
Outgo:					
Water in urine	[1]496.3	.....	.....	55.5	440.8
Organic matter in urine	[2]26.56	9.15	[3]7.59	[4]2.10	[5]7.72
Water of respiration and perspiration	681.4	.....	.....	76.2	605.2
Carbon dioxide	604.6	.....	164.9	.....	439.7
Total	1,808.86	9.15	172.49	133.80	1,493.42
Loss	1,264.06	9.15	172.49	133.80	948.62
Second day, Dec. 4–5, 1906:					
Income: Oxygen from air	564.5	.....	.....	.....	564.5
Outgo:					
Water in urine	525.6	.....	.....	58.8	466.8
Organic matter in urine	[2]37.95	13.07	[3]10.84	[4]3.01	[5]11.03
Water of respiration and perspiration	804.3	.....	.....	90.0	714.3
Carbon dioxide	594.9	.....	162.2	.....	432.7
Total	1,962.75	13.07	173.04	151.81	1,624.83
Loss	1,398.25	13.07	173.04	151.81	1,060.33

[1]Weight of urine less solid matter. Solid matter for Dec. 3–4 calculated from nitrogen by using ratio $\frac{\text{solid matter}}{\text{N}}$ for Dec. 4–5, 1906. (See table 15.)

[2]Sum of nitrogen, carbon, hydrogen, and oxygen.

[3]N×0.829 (see average ratio $\frac{\text{C}}{\text{N}}$, Benedict, Carnegie Inst. Wash. Pub. No. 77, 1907, table 202, p. 384).

[4]N×0.230 (computed ratio $\frac{\text{H}}{\text{N}}$ for experiment No. 81; see Benedict, Carnegie Inst. Wash. Pub. No. 77, 1907, table 168, pp. 258 and 259).

[5]N×0.844 (computed ratio $\frac{\text{O}}{\text{N}}$ for experiment No. 81; see Benedict, Carnegie Inst. Wash. Pub. No. 77, 1907, table 168, pp. 258 and 259).

TABLE 17.—*Elements and materials katabolized in body in fasting experiment with A. H. M. December 3–5, 1906.*[1]

Date.	Nitrogen.	Carbon.	Hydrogen.	Oxygen.	Water.	Protein.	Fat.	Carbohydrates (as glycogen).
1906.	*grams.*	*grams.*	*grams.*	*grams.*	*grams.*	*grams.*	*grams.*	*grams.*
Dec. 3–4.....	9.2	172.5	133.8	948.6	970.1	54.9	116.9	123.1
Dec. 4–5.....	13.1	173.0	151.8	1,060.3	1,128.1	78.4	145.3	47.6
Total, 2 days.	22.3	345.5	285.6	2,008.9	2,098.2	133.3	262.2	170.7

[1]See table 16 for methods of obtaining data.

TABLE 18.—*Comparison of energy computed from body material katabolized, with heat production as measured in fasting experiment with A. H. M., December 3–5, 1906.*

Date.	Energy computed from katabolized material.						(*g*) Total heat production as measured.	Heat production (computed) greater (+) or less (−) than heat production measured.	
	From body-protein.			(*d*) From body-fat.	(*e*) From body-glycogen.	(*f*) Total (*c*+*d*+*e*)		(*h*) Amount (*f*−*g*).	(*i*) Proportion. (*h*÷*g*).
	(*a*) Energy of protein katabolized.	(*b*) Potential energy of urine.	(*c*) Net energy (*a*−*b*).						
1906.	*cals.*	*cals.*	*cals.*	*cals.*	*cals.*	*cals.*	*cals.*	*cals.*	*p. ct.*
Dec. 3–4.....	310	76	234	1,115	516	1,865	1,830	+35	+1.9
Dec. 4–5.....	443	101	342	1,386	199	1,927	1,947	−20	−1.0
Total, 2 days.	753	177	576	2,501	715	3,792	3,777	+15	.....
Av. per day..	377	89	288	1,251	358	1,896	1,889	+ 8	+0.4

A reference to tables 15 and 16 shows that there was the usual rise in the nitrogen excretion on the second day of fasting. Of particular interest is the fact that the amount of glycogen katabolized, as shown in table 17, was 123.1 grams on the first day and 47.6 grams on the second day, this agreeing very well with the averages found for the other fasting subjects, namely, 110 grams on the first day and 40.3 grams on the second day.[1]

It is thus clear that the tendency to store glycogen shown in the experiment of November 21 to 23, 1905, was not at all characteristic of this subject.[2] This fact is further emphasized by the data obtained in the 1-day food experiment with an exclusively fat diet which followed the 2 days of fast, these results showing a further katabolism of glycogen amounting to 47.3 grams. Apparently the subject had by no means exhausted his glycogen supply at the end of the 2 days of fasting, even with a total output of 170.7 grams for the 2 fasting days.

Although it is contended that substances other than creatinine affect the Jaffé color reaction and accordingly the determinations of creatine in fasting urine can not be absolutely relied upon,[3] it should be noted that in this experiment, as in the earlier fasting experiments, there was evidence of preformed creatine in the urine. As a matter of fact, the 0.02 gram of creatine excreted on the second day of fast (see table 15) is much less than was observed in any of the other fasting experiments, the tendency in the earlier experiments being for this factor to increase somewhat on the second day rather than to decrease

[1] Benedict, Carnegie Inst. Wash. Pub. No. 77, 1907, p. 464, table 228.
[2] *Ibid.*, p. 222 *et seq.*
[3] Graham and Poulton, Proc. Royal Soc., ser. B, 1914, **87**, p. 205.

as in this experiment.[1] Inasmuch as so long a time has elapsed since the fasting experiment in December 1906 was made, and particularly as full reports of both short and long fasts have been given in recent publications,[2] it seems unnecessary to discuss in further detail the results of this experiment.

Following the 2-day fasting experiment with A. H. M., December 3 to 5, 1906, a 1-day food experiment was carried out December 5 to 6, in which the somewhat unfortunate attempt was made to have the subject take a considerable amount of olive oil in the form of mayonnaise dressing with lettuce and lemon juice. The results of this experiment are given in table 14. The total amount of food was relatively small, being only 213 grams; the amount of nitrogen in the food was negligible; the total fuel value was 1,109 calories, almost entirely from fat, and a little over one-half the amount necessary for maintenance. Under these conditions there was practically no change in the metabolism, for the slight plus and minus values observed in the several columns can not be considered as any larger than would be normally expected in daily fluctuations.

TABLE 19.—*A. H. M., December 5, 1906.* (12-hour periods, 9 a. m. to 9 p. m.)

Mayonnaise, lettuce, and lemon:

Amount, 213 grams; nitrogen, 0.37 gram; energy, 1,112 calories.

Fuel value: Total, 1,109 calories; from protein, 1 per cent; from fat, 98 per cent; from carbohydrates, 1 per cent.

Date.	Carbon dioxide.		Oxygen.		Heat.	
	Total.	Increase.	Total.	Increase.	Total.	Increase.
1906.						
Without food:	*grams.*	*grams.*	*grams.*	*grams.*	*cals.*	*cals.*
Dec. 3.....	311	..	275	..	965	..
Dec. 4.....,	309	..	285	..	948	..
Average.....	310	..	280	..	957	..
With food:[1].....						
Dec. 5.....	323	13	308	28	1,037	80

[1]Subject finished eating 48 minutes after the beginning of the period.

Since the influence of the food, if any, was slight, there is a possibility that the effect would be shown during the first few hours after the taking of the food, and would thereafter disappear or even be compensated for in a slight degree. It seemed best, therefore, to analyze this particular experiment further. Consequently the values were computed with a subdivision of the day into 12-hour periods. The results for the period from 9 a. m. to 9 p. m. are given in table 19. On this basis we find a slight increase for all three of the values given, amounting to 13 grams for the carbon-dioxide production, 28 grams for

[1]Benedict, Carnegie Inst. Wash. Pub. No. 77, 1907, p. 388, table 203.

[2]Benedict, Carnegie Inst. Wash. Pub. No. 77, 1907, and No. 203, 1915.

the oxygen consumption, and 80 calories for the heat production. Since all of the factors were distinctly higher than those found on either of the two fasting days, it is reasonable to suppose that the increases found represent a positive increment. It is possible that some of this increase may have been due to more activity on the food day in connection with receiving the food, eating it, returning the dishes, increased water drinking, and to defecation.[1]

TABLE 20.—*A. H. M., December 5, 1906. Sitting.* (2-hour periods.)

Mayonnaise, lettuce, and lemon:
Amount, 213 grams; nitrogen, 0.37 gram; energy, 1,112 calories.
Fuel value: Total, 1,109 calories; from protein, 1 per cent; from fat, 98 per cent; from carbohydrates, 1 per cent.
Basal value (Dec. 3 and 4, 1906), CO_2, 52 gms.; O_2, 47 gms.; heat, 164 cals.

Time elapsed since subject finished eating.	Carbon dioxide.		Oxygen.		Heat.	
	Total.	Increase.	Total.	Increase.	Total.	Increase.
	grams.	*grams.*	*grams.*	*grams.*	*cals.*	*cals.*
0 to 2 hours[1]	59	7	56	9	191	27
2 to 4 hours	64	12	69	22	181	17
4 to 6 hours	49	−3	46	−1	184	20
6 to 8 hours	51	−1	46	−1	169	5
Total...	223	15	217	29	725	69

[1]Finished eating mayonnaise, lettuce, and lemon 48 minutes after beginning of this period.

Finally, to subdivide this particular experiment still further, the results obtained for the first four 2-hour periods with food—*i. e.*, from 9 a. m. to 5 p. m.—are given in table 20; the basal values used are the average of those for the same period of time on the fasting days, and are given in table 21. On this basis it will be seen that there was a positive increase of 15 grams in the carbon-dioxide production in the four 2-hour periods following the ingestion of the oil, 29 grams in the oxygen consumption, and 69 calories in the heat production.

Special attention is given here to the presentation of the results of this particular experiment on account of the rather remarkable contention of Gigon[2] that, according to his experience, the ingestion of oil measurably depresses the metabolism. It is perhaps important to note that Gigon gave perfectly pure olive oil, while the oil in our experiment was mixed with a small proportion of lemon juice, egg yolk, and lettuce. While the two series of experiments are not perfectly comparable, nevertheless it is of significance that the depression noted by Gigon is at variance with the increment, slight though it is, shown in our results.

[1]See statistics for fasting and food days, Dec. 5–6, 1906, on p. 251.
[2]Gigon, Arch. f. d. ges. Physiol., 1911, **140**, p. 509.

TABLE 21.—*Basal metabolism of A. H. M., 9 a. m. to 5 p. m., December 3 and 4, 1906.*

Observation and date.	Duration.	9 a. m. to 11 a. m.	11 a. m. to 1 p. m.	1 p. m. to 3 p. m.	3 p. m. to 5 p. m.	Average.
1906.						
Carbon dioxide:		*grams.*	*grams.*	*grams.*	*grams.*	*grams.*
Dec. 3.....	9 a. m. to 5 p. m..	57	53	52	50	53
Dec. 4.....	9 a. m. to 5 p. m..	56	51	50	46	51
	Average.....	57	52	51	48	52
Oxygen:						
Dec. 3.....	9 a. m. to 5 p. m..	54	41	44	50	47
Dec. 4.....	9 a. m. to 5 p. m..	51	45	48	42	47
	Average.....	53	43	46	46	47
Heat:		*cals.*	*cals.*	*cals.*	*cals.*	*cals.*
Dec. 3.....	9 a. m. to 5 p. m..	181	167	151	152	163
Dec. 4.....	9 a. m. to 5 p. m..	183	168	...	145	165
	Average.....	182	168	151	149	164

In the 24-hour experiments thus far considered, the base-line was determined immediately prior to the ingestion of the food. In the 24-hour experiment with the subject A. H. M., February 2 to 3, 1906, in which crackers and milk were taken, such basal values were not available. A base-line obtained in an experiment on November 21 to 23, 1905, was therefore used, this being the nearest date on which a fasting value was obtained for this subject. Although the detailed discussion of the fasting experiment with A. H. M., December 3 to 5, 1906, shows that we have available still another fasting value, it did not seem desirable to average the two values for a base-line for this particular food experiment, inasmuch as the metabolism of this subject in the fall of 1905 was distinctly different from that in the latter part of 1906.

The results of the food experiment with A. H. M., February 2 to 3, 1906, are given in table 22, together with the average values for the fasting experiment of November 21 to 23, 1905. The values obtained on the two fasting days agree closely; the average heat production was 1,755 calories. With the ingestion of the crackers and milk, which had a total fuel value of about two-thirds of the daily requirement, the heat production was increased 239 calories, with a corresponding increase in the carbon-dioxide production and oxygen consumption. Here again it is extremely difficult to account for the unusually large increment. While it would normally be ascribed solely to the ingestion of the food, it is so at variance with the results obtained in almost all of the other experiments that one must question the reliability of the base-line. This experiment is an admirable illustration of the unsatisfactory use of 24-hour periods, particularly when there is a considerable interval

of time between the determination of the basal value and that determined after the ingestion of food.

TABLE 22.—*A. H. M., February 2–3, 1906.* (24-hour periods, 7 a. m. to 7 a. m.)

Crackers and milk:[1]

Amount, 1,150 grams; nitrogen, 7.34 grams; total energy, 1,314 calories.

Fuel value: Total, 1,250 calories; from protein, 15 per cent; from fat, 39 per cent; from carbohydrates, 46 per cent.

Date.	Nitrogen in urine.	Carbon dioxide.		Oxygen.		Heat.	
		Total.	Increase.	Total.	Increase.	Total.	Increase.
Without food:	*grams.*	*grams.*	*grams.*	*grams.*	*grams.*	*cals.*	*cals.*
Nov. 21–22, 1905...	9.11	535	...	517	..	1,729	...
Nov. 22–23, 1905...	13.05	524	...	527	..	1,781	...
Average.....	11.08	530	...	522	..	1,755	...
With food:							
Feb. 2–3, 1906.....	[2]12.38	679	149	602	80	1,994	239

[1]The food was eaten mostly in three portions, at 9 a. m., 1 p. m., and 6 p. m. Soda crackers and graham crackers were used with the milk.

[2]For period 6^h15^m a. m. Feb. 2 to 7 a. m. Feb. 3.

GENERAL CONCLUSIONS REGARDING USE OF 24-HOUR PERIODS.

From the foregoing discussion of the results of the experiments made on the 24-hour basis, it is seen that serious objections may properly be raised to this type of experiment, even though on first consideration the method may seem theoretically desirable. Experience with fasting men, both at Wesleyan University and in the Nutrition Laboratory,[1] has demonstrated that the metabolism progressively decreases as the fast continues. In the fast studied at the Nutrition Laboratory, in which accurate graphic records of the activity were obtained, this decrease in the fasting metabolism occurred with considerable uniformity at least 31 days, accompanied by a proportional loss in body-weight. In view of the steady loss in weight, it seems illogical to use values for a base-line which were determined under such conditions, particularly if the values are not compared on the basis of per kilogram of body-weight or per square meter of body-surface.

Furthermore, the depression in the metabolism due to fasting is abnormal, for evidently we have here a process entirely distinct from that due to the mere absence of food in the digestive tract. If we are to follow the contention of Johansson, we must consider the digestion of food and the daily body metabolism as two entirely independent processes, the body drawing continually upon its several depots for its immediate needs and the ingestion of food resulting in a separate process for replenishing these depots. At the time our studies of the

[1]Benedict, Carnegie Inst. Wash. Pub. No. 77, 1907, and No. 203, 1915.

basal metabolism begin (approximately 12 hours after the ingestion of food), active digestion has ordinarily ceased and the body deposits are presumably still in a normal condition, with the usual liberal supplies of glycogen, fat, and protein. During the post-absorptive condition the body begins to draw upon these deposits, particularly the glycogen, and in approximately 2 to 4 days of fasting the labile glycogen supply is heavily depleted; thereafter the metabolism remains essentially a protein-fat katabolism until food is again taken. As a result of these heavy drafts upon body material during fasting, we have, after one or two days of fast, a condition which represents at least the beginning of inanition. It would appear, therefore, that as soon as the general nutritive condition of the body is seriously affected by a disturbance in the proportion of body materials, we pass outside the field of measurement of the basal metabolism for studies on the influence of food. It is well known that one of the first effects of the ingestion of food after long inanition is the replenishment of the reserves of body material, and there is excellent evidence that this replenishment is accomplished by processes materially different from those occurring during ordinary digestion.

For the majority of experiments in which the effect of food is studied, a sharp differentiation between the post-absorptive condition and the beginning of inanition is unnecessary, but in certain of our experiments, especially those made in 24-hour periods, when the ingestion of food was 24, 36, 48, or even 60 and more hours after the last meal, we may have a condition of the body which distinctly approximates the first stages of inanition. The increment due to the ingestion of food would therefore be based upon abnormal values which would theoretically be somewhat lower than those ordinarily used for such studies. With so low a basal value, it frequently occurs that the stimulus of food simply compensates for the depressing influence of the previous fast and no increment in the metabolism is found. The effect obtained from the ingestion of food thus becomes a function of the duration of the fasting. For this reason the series of experiments in which the period of fasting was limited to two days are logically more satisfactory than those in which the subject fasted for a longer period.

The greatest practical difficulty encountered in the use of the 24-hour method of experimenting was the fact that after one or two days of fasting the subjects were frequently unable to eat appreciable quantities of food without distress. In the series of 2-day fasting experiments with college students at Wesleyan University, the experimental plan included the ingestion of unusually large amounts of food on the third day for the purpose of obtaining maximum effects. To our surprise and disappointment, it was found in many cases that the subjects could not eat large amounts of the food, or, having eaten it, they experienced distress, this being particularly true when large quantities

of a single food or pure food substance were given. Accordingly, the most of our experiments were made with relatively small amounts of food, with a correspondingly small fuel value, this fuel value occasionally representing but one-half or two-thirds of the daily needs. It was only when the period was somewhat curtailed and the observations confined to the night period that satisfactory base-lines could be obtained and the effect of the superimposed food definitely determined without the disturbing factor of the depression due to fasting. This latter plan of experimentation leads us naturally into the subdivision of the experimental day and a complete abandonment of the 24-hour method of experimenting.

From the foregoing considerations the only conclusion that can be reached is that the 24-hour period does not lend itself to a sharply defined study of the influence upon metabolism of the ingestion of food—first, because the establishment of a suitable basal value is extremely difficult, since each day of fasting shows a lowered metabolism as the specific result of the fasting; and second, because it has been proved physiologically impossible for many subjects, after two days of fasting, to take large amounts of food. These large amounts are particularly desirable for studying the influence upon the metabolism of a special food substance, especially as the increment, which is frequently slight, must be included in the total measurements for the 24-hour period and would thus in some cases, either wholly or in part, escape observation. This plan of experimentation thus defeats its own end, minimizing the effect of the food ingestion by a physiological reaction of the subject after fasting, and attenuating the frequently small increment in the metabolism due to the stimulating action of the food materials.

EXPERIMENTS OF APPROXIMATELY 8 HOURS.

The unsatisfactory termination of the attempts to use the 24-hour period in studying the influence of the ingestion of food upon metabolism led to a rearrangement of the experimental plans and the substitution of shorter experiments in which the metabolism was studied during that section of the digestive cycle when the maximum digestive activity would normally be expected. The experimental period would thus begin at approximately 9 o'clock in the morning and continue for about 8 hours.

CRITIQUE OF 8-HOUR METHOD.

In the 8-hour periods it was easier for the subject to follow a prescribed routine, such as sitting quietly in a chair without major muscular movement, than in the 24-hour periods. Furthermore, the uncertainty as to the length of time the subject slept was usually eliminated,

as the experiments were made in the daytime, when the men were for the most part awake. Theoretically the 8-hour period experimental plan would have been very satisfactory if it had been possible for the subjects to sleep throughout the period and thus provide an ideal condition for measuring the quiescent metabolism. With many people there is a tendency to sleep after eating; our subjects, however, were nearly all young, many of them being college students; sleep after eating was therefore not a common experience; hence a uniformity in sleep could not be accepted as certain.

These experiments were subdivided into 2-hour periods and in the Boston experiments into periods even shorter. There was therefore opportunity to secure information as to the time relations of the increase in the metabolism and possibly the maximum effect of the food.

Many of the disadvantages found with the 24-hour plan apply, also, to the 8-hour method. The possible errors in the measurements are the same as with the longer periods, especially with the large chamber at Wesleyan University, but with the shorter periods they assume more importance, since there is less opportunity for compensation and the total amounts are smaller. Furthermore, with the protein-rich diets, the total effect of the ingestion of food is not obtained, as it is unquestionably true that the stimulus frequently continues longer than 8 hours. During the 8-hour period only one or two meals can be given; the daily routine, with period of sitting or lying after food, must therefore be sacrificed.

Finally, if we use as a basis of comparison the metabolism determined in an 8-hour period without food, as was done in all of the Middletown experiments considered in this section and in some of the Boston experiments, we must still rely upon the determination of the base-line on one day and the observation of the food period on a subsequent day. In the 24-hour experimental plan the periods usually succeeded one another without interval, with the subject under careful surveillance the entire time and with like muscular activity throughout the days compared. In comparison experiments with an 8-hour basal unit, a period of some 8 to 14 hours, and sometimes one or more weeks, may intervene between the fasting and food measurements. During this time the subject is not under supervision; the activity and possibly the diet are therefore not known. The influence of a previous diet, muscular activity, and psychical excitement is as yet too uncertain for us to assume with surety that the basal metabolism will be alike during the periods compared, for although there is a general agreement between experiments made in this way, the katabolism does not remain exactly the same from day to day, either with or without food. Even when we average the results of a large number of fasting experiments and deduct this average from the results obtained after food to find the increase in the metabolism due to the ingestion of food, the errors

introduced may amount to a considerable percentage of the whole increment.

With large increments this possible difference in conditions would of course have less significance than with small increments. Consequently, while both the 24-hour and the 8-hour basal units permit reasonably satisfactory measurements of large increments in the metabolism as a result of the taking of food, they are open to very serious objection when used for the measurement of small increments.

DISCUSSION OF RESULTS OF 8-HOUR EXPERIMENTS WITHOUT FOOD.

The 8-hour experiments were made with the respiration calorimeters at Wesleyan University, Middletown, Connecticut, and the Nutrition Laboratory, Boston, Massachusetts. Inasmuch as the Boston 8-hour experiments differed somewhat in plan from those made in Middletown, the two groups of experiments will be discussed separately. Those carried out at Wesleyan University will first be considered, not only because they are first in chronological order, but also because the apparatus used and general technique, other than duration, were like those of the 24-hour experiments which have just been discussed.

In the collection of the data a number of basal values were secured, ranging over a period of several weeks or months, and not infrequently a year or more. Hence this collection of basal data has special importance as indicating the possibility of seasonal variation, and furthermore as showing the probable trend of the metabolism on any given day when the metabolism was measured in 4 to 6 consecutive 2-hour periods. The basal metabolism experiments only will be considered in this section; the results of the experiments with food will be given later in the discussion of the effect upon the metabolism of different classes of foods.

Middletown Calorimeter Experiments (8-Hour Basis).

The 8-hour plan was used successfully in a large number of experiments at Wesleyan University in which the basal metabolism was studied for approximately this period on one day and on a subsequent day the metabolism after the ingestion of food was found for a corresponding period. The increment due to the food was then determined by comparing the results obtained. Uniformity in the degree of muscular repose was even more important in these shorter experiments than it was in the 24-hour experiments, and it was necessary to reduce the muscular activity to a minimum so far as possible.

The results of the experiments are given in tables 23 to 26. These tables show the experimental day divided into 2-hour periods, the data for the individual periods being placed according to the time the observations were made. The experiments usually began about 9 a. m.,

and the values in the "first period" commonly represent the values obtained approximately in the period between 9 a. m. and 11 a. m. Averages are given for each period and also for each experimental day. The carbon-dioxide production and oxygen consumption are shown in two significant figures and the heat production in three significant figures. The weighings of the carbon-dioxide are accurate to the tenth of a gram, but as there is always an uncertainty in determining the residual amount of carbon dioxide in a chamber of so large a volume as

TABLE 23.—*Basal metabolism of A. L. L. at different times of day in calorimeter experiments, subject in sitting position.—Middletown.* (Values per 2 hours.)

Date.	Duration.	First two hours.[1]	Second two hours.	Third two hours.	Fourth two hours.	Fifth two hours.	Sixth two hours.	Average
1906.	*Carbon dioxide.*	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*
Feb. 7....	10^h00^ma.m. to 6^h00^mp.m.	48	46	46	48	..	..	47
Feb. 9....	9 00 a.m. to 5 00 p.m.	47	47	45	47	..	..	47
Feb. 20....	8 45 a.m. to 4 45 p.m.	48	45	48	..	..	..	47
Apr. 3...	8 40 a.m. to 12 40 p.m.	48	50	..	..	..	..	49
Apr. 6....	1 15 p.m. to 9 15 p.m.	..	..	45	46	46	43	45
	Average (1906).....	48	47	46	47	46	43	47
1907.								
Apr. 20....	7^h45^ma.m. to 3^h45^mp.m.	56	53	54	55	..	..	55
May 4...	8 15 a.m. to 4 15 p.m.	54	51	50	50	..	..	51
	Average (1907).....	55	52	52	53	..	..	53
1906.	*Oxygen.*							
Feb. 7....	10^h00^ma.m. to 6^h00^mp.m.	40	40	44	45	..	..	42
Feb. 9....	9 00 a.m. to 5 00 p.m.	36	44	39	44	..	..	41
Feb. 20....	8 45 a.m. to 4 45 p.m.	40	36	46	43	..	..	41
Apr. 3....	8 40 a.m. to 12 40 p.m.	39	47	..	..	..	..	43
Apr. 6....	1 15 p.m. to 9 15 p.m.	..	..	38	46	43	39	42
	Average (1906).....	39	42	42	45	43	39	42
1907.								
Apr. 20....	7^h45^ma.m. to 3^h45^mp.m.	49	48	..	48	..	..	48
May 4...	8 15 a.m. to 4 15 p.m.	45	43	43	40	..	..	43
	Average (1907).....	47	46	43	44	..	..	46
1906.	*Heat.*	*cals.*	*cals.*	*cals.*	*cals.*	*cals.*	*cals.*	*cals.*
Feb. 7....	10^h00^ma.m. to 6^h00^mp.m.	164	145	140	150	...	...	150
Feb. 9....	9 00 a.m. to 5 00 p.m.	162	145	142	147	...	...	149
Feb. 20....	8 45 a.m. to 4 45 p.m.	151	148	150	163	...	...	153
Apr. 3....	8 40 a.m. to 12 40 p.m.	147	147	...	...	...	...	147
Apr. 6....	1 15 p.m. to 9 15 p.m.	...	...	146	146	140	136	142
	Average (1906).....	156	146	145	152	140	136	148
1907.								
Apr. 20....	7^h45^ma.m. to 3^h45^mp.m.	169	169	178	167	...	...	171
May 4...	8 15 a.m. to 4 15 p.m.	[2]171	[2]160	[2]154	[2]148	...	...	[2]158
	Average (1907).....	170	165	166	158	...	...	165

[1]The beginning of the "First two hours" was for this subject between 7^h45^m a. m. and 10 a. m.
[2]Heat eliminated corrected for change in body-weight, but not for change in body-temperature.

that of the Middletown calorimeter (approximately 5,000 liters), it seems permissible to record the results only to the nearest gram.

With at least three of our subjects, A. L. L., A. H. M., and H. R. D., five or more basal values were obtained. (See tables 23, 24, and 25.) With both A. L. L. and A. H. M., difficulty was experienced in finding an average value, since with both subjects there appeared to be a distinct variation in the metabolism as measured at different times. For example, with A. L. L., the basal values determined from February 7 to April 6, 1906, inclusive, were on an entirely different level from those found a year later. This is shown not only in the carbon-dioxide production, but also in the oxygen consumption and heat production.

TABLE 24.—*Basal metabolism of A. H. M. at different times of day in calorimeter experiments, subject in sitting position.—Middletown.* (Values per 2 hours.)

Date.	Duration.	First two hours.[1]	Second two hours.	Third two hours.	Fourth two hours.	Fifth two hours.	Sixth two hours.	Average.
1906.	*Carbon dioxide.*	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*
Feb. 12....	9h30ma.m. to 5h30mp.m...	44	45	43	45	..	..	44
Feb. 14....	9 00 a.m. to 5 00 p.m...	50	44	44	46	..	..	46
	Average (1906).....	47	45	44	46	..	..	45
1906.								
Nov. 22...	9h04ma.m. to 9h04mp.m...	54	51	51	49	48	47	50
1907.								
Mar. 6...	9h15ma.m. to 5h15mp.m...	52	51	49	54	..	..	52
Mar. 9...	9 00 a.m. to 5 00 p.m...	50	49	50	52	..	..	50
	Average (1906–1907).	52	50	50	52	48	47	51
1906.	*Oxygen.*							
Feb. 12....	9h30ma.m. to 5h30mp.m...	37	39	41	43	..	..	40
Feb. 14....	9 00 a.m. to 5 00 p.m...	40	35	43	40	..	..	40
	Average (1906).....	39	37	42	42	..	..	40
1906.								
Nov. 22...	9h04ma.m. to 9h04mp.m...	48	44	45	42	..	43	44
1907.								
Mar. 6...	9h15ma.m. to 5h15mp.m...	43	48	44	51	..	..	47
Mar. 9...	9 00 a.m. to 5 00 p.m...	41	44	47	47	..	..	45
	Average (1906–1907).	44	45	45	47	..	43	45
1906.	*Heat.*	*cals.*	*cals.*	*cals.*	*cals.*	*cals.*	*cals.*	*cals.*
Feb. 12....	9h30ma.m. to 5h30mp.m...	156	132	135	131	...	...	139
Feb. 14....	9 00 a.m. to 5 00 p.m...	163	146	131	138	...	...	145
	Average (1906).....	160	139	133	135	...	...	142
1906.								
Nov. 22...	9h04ma.m. to 9h04mp.m...	172	157	158	158	155	149	158
1907.								
Mar. 6...	9h15ma.m. to 5h15mp.m...	169	159	162	167	...	...	164
Mar. 9...	9 00 a.m. to 5 00 p.m...	167	162	159	168	...	...	164
	Average (1906–1907).	169	159	160	164	155	149	162

[1]The beginning of the" First two hours" was for this subject between 9 a. m. and 9h 30m a.m.

Hence the values for 1906 and 1907 are averaged separately. The average carbon-dioxide production per two hours for A. L. L. during the spring of 1906 was 47 grams; a year later the average of two experiments showed 53 grams. Similar variations were observed in the oxygen consumption, the average value for 1906 being 42 grams, while that for 1907 was 46 grams. The average heat production was 148 calories in 1906 and 165 calories in 1907.

TABLE 25.—*Basal metabolism of H. R. D. at different times of day in calorimeter experiments, subject in sitting position.—Middletown.* (Values per 2 hours.)

Date.	Duration.	First two hours.[1]	Second two hours.	Third two hours.	Fourth two hours.	Fifth two hours.	Sixth two hours.	Average
1906.	*Carbon dioxide.*	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*
Feb. 6....	9^h46^ma.m. to 5^h46^mp.m..	46	47	50	47	..	..	47
Feb. 10....	9 15 a.m. to 5 15 p.m..	48	48	45	47	..	..	47
Apr. 4....	8 37 a.m. to 12 37 p.m..	48	45	..	..	..	..	46
Apr. 10....	1 00 p.m. to 9 00 p.m..	..	..	47	47	48	48	48
Apr. 20....	1 30 p.m. to 9 00 p.m..	..	..	[2]44	48	46	48	47
	Average.....	47	47	47	47	47	48	47
	Oxygen.							
Feb. 6....	9^h46^ma.m. to 5^h46^mp.m..	42	39	48	40	..	..	42
Feb. 10....	9 15 a.m. to 5 15 p.m..	39	40	40	44	..	..	41
Apr. 10....	1 00 p.m. to 9 00 p.m..	..	..	39	44	42	44	42
Apr. 20....	1 30 p.m. to 9 00 p.m..	..	..	[2]41	44	48	44	44
	Average.....	41	40	42	43	45	44	42
	Heat.	*cals.*	*cals.*	*cals.*	*cals.*	*cals.*	*cals.*	*cals.*
Feb. 6....	9^h46^ma.m. to 5^h46^mp.m..	146	137	148	142	...	...	143
Feb. 10....	9 15 a.m. to 5 15 p.m..	150	144	141	137	...	...	143
Apr. 4....	8 37 a.m. to 12 37 p.m..	155	141	...	...	...	...	148
Apr. 10....	1 00 p.m. to 9 00 p.m..	...	...	159	156	138	149	151
Apr. 20....	1 30 p.m. to 9 00 p.m..	...	...	[2]148	150	140	134	143
	Average.....	150	141	149	146	139	142	146

[1]The beginning of the "First two hours" was for this subject approximately between 8^h30^m a. m. and 9^h45^m a. m.

[2]Calculated to 2-hour basis; measured in period of $1\frac{1}{2}$ hours.

With the subject A. H. M. the basal metabolism determined on 2 days in the middle of February 1906 showed a distinctly lower value than the basal metabolism determined in the fall of 1906 and spring of 1907. Thus, the average carbon-dioxide production for February 1906 was 45 grams, the oxygen consumption was 40 grams, and the heat production was 142 calories, while the average values for the three experiments in the period from November 22, 1906, to March 9, 1907, was 51 grams for the carbon-dioxide production, 45 grams for the oxygen consumption, and 162 calories for the heat production. It is thus clear that with these two subjects we have a variation of at least 10 per cent, as shown by these duplicate experiments.

With both subjects there was an increase in weight between the two groups of experiments. With A. L. L. the weight in 1906 averaged 67 kilograms and in 1907 it averaged 73.4 kilograms, this increment in weight being approximately proportional to the increase noted in the metabolism. With A. H. M. the weight increased from 63.8 kilograms to 66.2 kilograms; this slight increase was by no means proportional to the increase in the metabolism. Although the values for the metabolism have not been presented on the basis of per kilogram of body-weight or per square meter of body-surface, it is obvious that with this latter subject the metabolic level was distinctly higher in the second group of experiments than in the first group. Accordingly, in determining the increment in the metabolism with food, it is impossible to use an average of these basal values for comparison and we must resort to a selection of data from the experiments made nearest in point of time to the food experiments.

A general examination of tables 23, 24, and 25 shows that there is a distinct tendency for the 2-hour values to diminish as the day proceeds. Not infrequently the value for the first period of the day is somewhat higher than the others. Inasmuch as nearly all of our experiments were planned on the four 2-hour period basis, this point demands special consideration. The general picture for the two subjects A. L. L. and A. H. M. (see tables 23 and 24) shows a definite though slight tendency for the metabolism to decrease as the day progresses, this being especially noticeable in the fifth and sixth periods. On the other hand, the average carbon-dioxide values for H. R. D. (table 25) are constant, while the oxygen values show, if anything, a slight increase; the values for the heat production are irregular. It should be remembered, however, that in several instances, and particularly with H. R. D., the average values for the later periods are not derived from values obtained on the same day as the averages for the preceding periods, and hence they do not represent consecutive 2-hour periods in all instances. Furthermore, while there are variations in individual periods, it is the average of all these values that is being discussed, and these averages indicate truthfully the general trend of the metabolism. The values for the subjects H. C. K., Dr. R., E. H. B., A. W. W., and H. B. W. (see table 26) usually show more constancy in the first four periods of the day, although in a number of cases those for the fourth period are high, especially for the heat production.

The average basal metabolism for each subject is recorded in table 27, in which are given the average values for the body-weight, the carbon dioxide produced, oxygen consumed, heat produced, and nitrogen excreted in the urine per 2-hour period. The nitrogen values are included in this table as an indication of the probable protein katabolism in the experiments. In no instance was the diet controlled prior to the experiment, although usually no food had been taken for at least

TABLE 26.—*Basal metabolism at different times of day in calorimeter experiments, subjects in sitting position.—Middletown.* (Values per 2 hours.)

Subject and observation.	Date.	Duration.	First two hours.[1]	Second two hours.	Third two hours.	Fourth two hours.	Average.
H. C. K.	1906.		*gm.*	*gm.*	*gm.*	*gm.*	*gm.*
Carbon dioxide.	May 3	9h05m a.m. to 5h05m p.m.	52	47	52	53	51
Oxygen.....	May 3	9 05 a.m. to 5 05 p.m.	47	42	51	47	47
			cals.	*cals.*	*cals.*	*cals.*	*cals.*
Heat.....	May 3	9 05 a.m. to 5 05 p.m.	175	161	152	167	164
DR. R.	1907.		*gm.*	*gm.*	*gm.*	*gm.*	*gm.*
Carbon dioxide.	Feb. 20	8h58m a.m. to 4h58m p.m.	46	49	48	50	48
Oxygen.....	Feb. 20	8 58 a.m. to 4 58 p.m.	..	43	..	48	45
			cals.	*cals.*	*cals.*	*cals.*	*cals.*
Heat.....	Feb. 20	8 58 a.m. to 4 58 p.m.	[2]147	[2]141	[2]146	[2]148	[2]146
E. H. B.			*gm.*	*gm.*	*gm.*	*gm.*	*gm.*
Carbon dioxide.	Mar. 7	9h01m a.m. to 5h01m p.m.	60	57	58	58	58
	Mar. 13	8 55 a.m. to 4 55 p.m.	59	55	60	57	58
		Average.....	60	56	59	58	58
Oxygen.....	Mar. 7	9h01m a.m. to 5h01m p.m.	47	49	50	51	49
	Mar. 13	8 55 a.m. to 4 55 p.m.	48	41	53	46	47
		Average.....	48	45	52	49	48
			cals.	*cals.*	*cals.*	*cals.*	*cals.*
Heat.....	Mar. 7	9h01m a.m. to 5h01m p.m.	183	179	173	182	179
	Mar. 13	8 55 a.m. to 4 55 p.m.	193	169	185	169	179
		Average.....	188	174	179	176	179
A. W. W.			*gm.*	*gm.*	*gm.*	*gm.*	*gm.*
Carbon dioxide.	Mar. 15	9h05m a.m. to 5h05m p.m.	48	55	50	50	51
	Mar. 21	8 29 a.m. to 4 29 p.m.	50	51	49	48	50
		Average.....	49	53	50	49	50
Oxygen.....	Mar. 15	9h05m a.m. to 5h05m p.m.	40	42	43	43	42
	Mar. 21	8 29 a.m. to 4 29 p.m.	39	42	40	40	40
		Average.....	40	42	42	42	41
			cals.	*cals.*	*cals.*	*cals.*	*cals.*
Heat.....	Mar. 15	9h05m a.m. to 5h05m p.m.	166	164	154	153	159
	Mar. 21	8 29 a.m. to 4 29 p.m.	165	158	140	144	152
		Average.....	166	161	147	149	155
H. B. W.			*gm.*	*gm.*	*gm.*	*gm.*	*gm.*
Carbon dioxide.	Mar. 22	8h31m a.m. to 4h31m p.m.	59	59	58	56	58
	Apr. 4	8 32 a.m. to 4 32 p.m.	55	54	53	53	54
	Apr. 26	8 05 a.m. to 12 05 p.m.	59	56	..	..	57
		Average.....	58	56	56	55	56
Oxygen.....	Mar. 22	8h31m a.m. to 4h31m p.m.	48	50	51	51	50
	Apr. 4	8 32 a.m. to 4 32 p.m.	47	44	45	49	46
	Apr. 26	8 05 a.m. to 12 05 p.m.	51	50	..	..	50
		Average.....	49	48	48	50	49
			cals.	*cals.*	*cals.*	*cals.*	*cals.*
Heat.....	Mar. 22	8h31m a.m. to 4h31m p.m.	[2]190	[2]171	[2]172	[2]171	[2]176
	Apr. 4	8 32 a.m. to 4 32 p.m.	160	158	159	154	158
	Apr. 26	8 05 a.m. to 12 05 p.m.	166	166	...	...	166
		Average.....	172	165	166	163	167

[1]The beginning of the "First two hours" was for the subjects in this table between 8h05m a. m. and 9h05m a. m.

[2]Heat eliminated corrected for change in body-weight but not for change in body-temperature.

TABLE 27.—*Summary of average values for basal metabolism determined for subjects in sitting position in calorimeter experiments.—Middletown.* (Amounts per 2 hours.)

Subject.	Average body-weight without clothing.	Carbon dioxide.	Oxygen.	Heat.	Nitrogen[1] excreted in urine.
	kilos.	*grams.*	*grams.*	*cals.*	*gram.*
A. L. L., 1906..	67.0	47	42	148	0.72
1907..	73.4	53	46	165	
A. H. M., 1906.	63.8	45	40	142	.94
1907.	66.2	51	45	162	
H. R. D.....	58.2	47	42	146	.75
H. C. K.....	73.6	51	47	164	.82
Dr. R.....	50.4	48	45	[2]146	.69
E. H. B.....	72.1	58	48	179	.89
A. W. W.....	57.7	50	41	155	.65
H. B. W.....	62.4	56	49	167	.85

[1]Includes all nitrogen values obtained with these subjects for the periods in which the basal metabolism was determined and on any first day of fasting. See table 28.
[2]Heat eliminated corrected for change in body-weight, but not for change in body-temperature.

TABLE 28.—*Nitrogen excreted in urine during experiments without food.* (Amounts per 2 hours.)

Subject.	Date.	Amount.	Subject.	Date	Amount.
		grams.			*grams.*
A. L. L.....	Apr. 27, 1904.....	[1]1.03	H. R. D....	Dec. 5–6, 1905....	[1]1.10
	Dec. 16, 1904.....	[1].83		Apr. 4, 1906.....	.52
	Feb. 20, 1906.....	.78		Apr. 10–11, 1906..	.70
	Apr. 3, 1906.....	.65		Apr. 20, 1906.....	.69
	Apr. 6, 1906.....	.36		Average.....	.75
	Apr. 20, 1907.....	.71			
	May 4, 1907.....	.71	Dr. R.....	Feb. 20, 1907.....	.69
	Average.....	.72	E. H. B....	Mar. 7, 1907.....	.88
A. H. M....	Nov. 21–22, 1905..	[1].76		Mar. 13, 1907.....	.89
	Feb. 14, 1906.....	.94		Average.....	.89
	Nov. 22, 1906.....	1.08			
	Dec. 3–4, 1906....	[2].76	A. W. W...	Mar. 15, 1907.....	.55
	Mar. 6, 1907.....	1.06		Mar. 21, 1907.....	.75
	Mar. 9, 1907.....	1.06		Average.....	.65
	Average.....	.94			
H. C. K....	Nov. 24–25, 1905..	[1].78	H. B. W....	Mar. 22, 1907.....	.85
	May 3, 1906.....	.85		Apr. 4, 1907.....	.82
	Average.....	.82		Apr. 26, 1907.....	.87
				Average.....	.85

[1]Benedict, Carnegie Inst. Wash. Pub. No. 77, 1907. Excepting the results with A. L. L. April 27 and Dec. 16, 1904, these values taken from Pub. No. 77 represent the 24 hours of the first fasting day.
[2]Determined in 24 hours of first day of fast.

12 hours. These average nitrogen values are also shown in table 28, together with all of the available nitrogen values for the individual experiments included in tables 23, 24, 25, and 26. For the subjects A. L. L., A. H. M., H. C. K., and H. R. D., these values are supplemented by other values drawn from experiments not discussed in this publication. The detailed results in table 28 show, particularly with H. R. D. and A. L. L., a much wider variation than would normally be expected. Thus on the second day with H. R. D. April 4, 1906, the nitrogen excreted was less than half that excreted on December 5–6, 1905. A still more striking variation is that on April 6, 1906, with A. L. L., which is approximately one-third of that found on April 27, 1904, with the same subject. In general the variations from the average value are not sufficiently great to affect seriously the computations of the energy transformations in which it is desirable to apportion the energy between the protein and the other constituents of the metabolism.

General Conclusions Regarding 8-Hour Experiments in Middletown.

The general conclusion may thus be drawn, from an inspection of the data in tables 23, 24, 25, and 26, that for the first four 2-hour periods in the daytime, beginning at approximately 9 o'clock, with the subject in the post-absorptive condition, there is usually a somewhat high value in the first period of the day, followed by a reasonable constancy in the next three periods; in the few values recorded for the fifth and sixth periods, a tendency is shown for the metabolism to decrease with two subjects and to increase with a third subject. There is, of course, a possibility that the increases noted in some of the values during the later periods were due to restlessness of the subject as a result of the long sojourn in the chamber. On the other hand, there was certainly no external muscular activity of sufficient moment which would justify us in assuming that the measurement of the metabolism was vitiated in this way.

In using the data for basal values in the measurement of the influence of the ingestion of food, it is evident that when major increments are to be expected one may disregard the slight variations noted throughout the day in these tables and consider that the metabolism is essentially constant. This is in line with the earlier interpretation of basal values given by us in a previous publication,[1] which were obtained in duplicate experiments during the daytime, but occasionally during the sleeping period. A close agreement was there noted in the average values for the carbon-dioxide production, oxygen consumption, and heat production for the experiments compared. It should be remembered, however, that the average values referred to were for fairly long periods, *i. e.*, from 6 to 12 hours, and in at least one instance, for 4

[1]Benedict and Carpenter, Carnegie Inst. Wash. Pub. No. 126, 1910, p. 107, table 45.

days. While these values do indicate, therefore, a constancy in the metabolism for periods of this length, they give no evidence as to the possibilities of variations from period to period, such as those shown in tables 23, 24, 25, and 26.

In considering the values for the metabolism given in these basal tables, it should be remembered that the subjects were allowed the restricted freedom of the respiration chamber. It was impossible to require them to remain absolutely quiet or to assume a definite position for the period of 8 to 12 hours during which they were under observation. The muscular activity was kept at a minimum, however, and every attempt was made to have it uniform from day to day. While we believe that the values given represent a higher metabolism than the strictly basal metabolism of the individuals studied—*i. e.*, the metabolism with muscular repose and without food in the stomach—we feel that our use of them for comparison with the results of the subsequent food experiments is permissible, in the absence of less contaminated data, inasmuch as the routine and degree of muscular activity on the food days were very similar to those on the days when the basal metabolism was obtained.

Boston Calorimeter Experiments (8-Hour Basis).

In the experiments on the 8-hour plan in Boston, both the chair calorimeter and the bed calorimeter were used for measuring the metabolism. In the chair calorimeter, which was the first calorimeter constructed in the Nutrition Laboratory, the subject remained comfortably seated in an arm chair throughout an experiment. The total volume of the air in the chamber was approximately 1,400 liters; the air space and body activity were therefore much more restricted than in the Middletown calorimeter, in which the chamber had a volume of approximately 5,000 liters, affording opportunity for considerable movement. In the chair calorimeter the water bottles and urine bottles were conveniently placed near the subject and it was unnecessary to rise from the chair for their use; there was, however, some minor muscular activity, such as the motions accompanying the reading of a book, and similar movements. The actual activity in the chair-calorimeter experiments was very considerably less than that in the calorimeter experiments in Middletown, save when the latter experiments were made during the periods from 11 p. m. to 7 a. m. with the subject asleep in bed.

The chamber of the bed calorimeter was even smaller than that of the chair calorimeter, being approximately 950 liters in volume. The subject lay upon a cot and it was impossible for him to sit up or to move very much except to turn the body from side to side. The food aperture was never opened during an experiment. Occasionally

the subject drank water, and urine collections were sometimes made. During the greater part of the time the subject read quietly or slept. The results of the experiments with the bed calorimeter may thus consistently be used as evidence of an approximate basal metabolism—*i. e.*, the minimum metabolism with nearly complete muscular repose and in the post-absorptive condition.

All of the Boston experiments were made with the subject in the post-absorptive condition (12 hours after food). Furthermore, it was possible in these experiments to obtain a graphic record of the muscular activity by means of a pneumograph fastened around either the chest or the thighs and connected with a tambour outside the chamber. Inasmuch as the air volume of the two calorimeters used in Boston was smaller than that of the Middletown apparatus and the subject was considerably quieter, the measurements could be made with a higher degree of accuracy, especially as the activity was controlled by means of the graphic record. It was thus possible to subdivide the experiment into shorter periods and to obtain values per hour or per three-quarters of an hour instead of for 2 hours, as with the Middletown experiments.

While the duration of the Boston experiments was approximately the same as that of the Middletown experiments considered in this section, the general plan was changed in that the basal metabolism was first determined for a number of periods, then the food was given, and the experiment was continued for the remainder of the 8 hours. The basal metabolism and the metabolism after food were thus determined on the same day in continuous measurements. This plan was followed with nearly all of the food materials studied except beefsteak.

Certain of the experiments were continued for periods longer than 8 hours in order to obtain further information as to the probable variation from hour to hour. In many instances observations were made with the same subject at intervals for many months or even years; a hint could thus be obtained as to the possibility of seasonal or yearly variations.

The first extended experiment in which the chair calorimeter was used was that made with J. R., December 3, 1908, although this apparatus had been tested in shorter experiments prior to this date. The results of this experiment, together with those of five other experiments with the same subject, are given in table 29. In this and the succeeding tables, the day is divided into hour periods, the results obtained in the individual periods being placed in the table according to the time the observations were made. Average values are also given both for the experimental periods and for the values obtained in the individual periods in all of the experiments. In considering the latter averages, it should be borne in mind that some of the individual values were determined several months or years apart.

TABLE 29.—*Basal metabolism of J. R. at different times of day in chair-calorimeter experiments.—Boston.* (Values per hour.)

Date.	Observation and duration.	First hour.[1]	Second hour.	Third hour.	Fourth hour.	Fifth hour.	Sixth hour.	Average.
1908.	*Carbon dioxide.*	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*
Dec. 3	9h12m a.m. to 3h12m p.m.	28.0	28.5	26.5	25.5	25.5	25.5	26.5
Dec. 17	9 01 a.m. to 3 01 p.m.	27.5	27.5	28.5	27.5	27.5	26.5	27.5
1910.								
Mar. 21	8 49 a.m. to 10 49 a.m.	26.0	26.0	....	....	....	....	26.0
May 5	8 38 a.m. to 10 38 a.m.	27.0	26.5	....	....	....	....	27.0
May 10	8 37 a.m. to 10 37 a.m.	27.0	28.0	....	....	....	....	27.5
May 13	8 57 a.m. to 10 57 a.m.	25.5	26.5	....	....	....	....	26.0
	Average	27.0	27.0	27.5	26.5	26.5	26.0	27.0
1908.	*Oxygen.*							
Dec. 3	9h12m a.m. to 3h12m p.m.	24.0	23.5	23.0	23.0	22.5	23.5	23.5
Dec. 17	9 01 a.m. to 3 01 p.m.	24.0	22.5	24.0	24.5	24.5	23.0	24.0
1910.								
Mar. 21	8 49 a.m. to 10 49 a.m.	21.5	21.0	....	....	....	....	21.0
May 5	8 38 a.m. to 10 38 a.m.	22.0	23.5	....	....	....	....	23.0
May 10	8 37 a.m. to 10 37 a.m.	....	24.0	....	....	....	....	24.0
May 13	8 57 a.m. to 10 57 a.m.	20.0	23.0	....	....	....	....	21.5
	Average	22.5	23.0	23.5	24.0	23.5	23.5	23.0
1908.	*Heat.*	*cals.*	*cals.*	*cals.*	*cals.*	*cals.*	*cals.*	*cals.*
Dec. 3	9h12m a.m. to 3h12m p.m.	[2]74	[2]75	[2]72	[2]76	[2]73	[2]73	[2]74
Dec. 17	9 01 a.m. to 3 01 p.m.	78	88	81	89	77	82	83
1910.								
Mar. 21	8 49 a.m. to 10 49 a.m.	79	81	....	....	....	....	80
May 5	8 38 a.m. to 10 38 a.m.	[2]74	[2]72	....	....	....	....	[2]73
May 10	8 37 a.m. to 10 37 a.m.	[2]71	[2]72	....	....	....	....	[2]72
May 13	8 57 a.m. to 10 57 a.m.	[2]82	[2]78	....	....	....	....	[2]80
	Average	76	78	77	83	75	78	77

[1]The beginning of the "First hour" was for this subject approximately between 8h30m a. m. and 9h15m a. m.

[2]Heat eliminated corrected for change in body-weight, but not for change in body-temperature.

The carbon-dioxide production with this subject was remarkably constant, as shown by the figures in both sets of averages. Individual variations may be noted, however, the values being in two cases as high as 28.5 grams per hour and in several instances as low as 25.5 grams. On the whole, the agreement shows rather remarkable uniformity, not only from month to month but from hour to hour. The same uniformity is, in general, shown in the averages for the oxygen consumption. The range in the individual values is from 20 grams to 24.5 grams. Considerable variation appears in the values for the heat production. Thus in the fourth hour a value as high as 89 calories was found, while in another instance we have a value as low as 71 calories. When the average values alone are considered, the variations from hour to hour are found to be quite small, with the single exception of the average for the fourth hour. In general, this subject produced 77 calories of heat per hour.

TABLE 30.—*Basal metabolism of F. M. M. at different times of day in chair-calorimeter experiments.—Boston.* (Values per hour.)

Date.	Observation and duration.	First hour.[1]	Second hour.	Third hour.	Fourth hour.	Fifth hour.	Sixth hour.	Seventh hour.	Average.
1908.	*Carbon dioxide.*	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*
Dec. 9	8^h36^m a.m. to 2^h36^m p.m.	27.0	24.5	26.0	24.0	24.5	24.0	....	25.0
Dec. 14	11 02 a.m. to 4 02 p.m.	....	....	26.0	26.0	29.0	26.5	24.5	26.5
Dec. 18	9 15 a.m. to 3 15 p.m.	24.5	27.0	25.5	25.0	25.0	27.0	....	25.5
Dec. 22	8 40 a.m. to 2 40 p.m.	24.5	24.5	25.5	24.5	23.5	25.0	....	24.5
Dec. 29	10 00 a.m. to 4 00 p.m.	....	28.5	26.0	26.0	24.0	23.5	25.0	25.5
1909.									
Jan. 6	8 50 a.m. to 2 50 p.m.	25.5	26.0	24.5	25.0	25.0	25.5	....	25.5
Jan. 11	9 06 a.m. to 3 06 p.m.	26.0	22.5	24.0	24.0	23.5	23.0	....	24.0
Apr. 8	10 24 a.m. to 1 24 p.m.	....	23.5	25.0	21.5	....	....	....	23.5
1910.									
Jan. 31	9 30 a.m. to 11 30 a.m.	29.0	27.0	....	....	....	....	....	28.0
Feb. 2	8 51 a.m. to 10 51 a.m.	27.5	27.5	....	....	....	....	....	27.5
Feb. 8	9 38 a.m. to 11 38 a.m.	24.5	26.5	....	....	....	....	....	25.5
Feb. 19	9 03 a.m. to 11 03 a.m.	26.0	25.0	....	....	....	....	....	25.5
	Average	26.0	25.5	25.5	24.5	25.0	25.0	25.0	25.5
1908.	*Oxygen.*								
Dec. 9	8^h36^m a.m. to 2^h36^m p.m.	23.5	19.0	22.5	19.5	23.0	20.0	....	21.0
Dec. 14	11 02 a.m. to 4 02 p.m.	....	....	25.5	22.5	24.5	23.5	22.0	23.5
Dec. 18	9 15 a.m. to 3 15 p.m.	19.5	26.5	23.5	24.0	22.5	24.5	....	23.5
Dec. 22	8 40 a.m. to 2 40 p.m.	20.0	19.5	23.0	23.0	20.5	22.0	....	21.5
Dec. 29	10 00 a.m. to 4 00 p.m.	....	24.0	23.0	22.0	23.0	20.0	22.0	22.5
1909.									
Jan. 6	8 50 a.m. to 2 50 p.m.	23.0	23.0	21.5	25.5	23.5	22.5	....	23.0
Jan. 11	9 06 a.m. to 3 06 p.m.	22.0	19.5	22.5	21.0	22.0	20.0	....	21.0
Apr. 8	10 24 a.m. to 1 24 p.m.	....	20.5	20.5	21.0	....	....	....	20.5
1910.									
Jan. 31	9 30 a.m. to 11 30 a.m.	24.5	23.5	....	....	....	....	....	24.0
Feb. 2	8 51 a.m. to 10 51 a.m.	22.0	24.5	....	....	....	....	....	23.5
Feb. 8	9 38 a.m. to 11 38 a.m.	22.0	23.0	....	....	....	....	....	22.5
Feb. 19	9 03 a.m. to 11 03 a.m.	22.5	....	....	....	....	....	....	22.5
	Average	22.0	22.5	23.0	22.5	22.5	22.0	22.0	22.5
1908.	*Heat.*	*cals.*	*cals.*	*cals.*	*cals.*	*cals.*	*cals.*	*cals.*	*cals.*
Dec. 9	8^h36^m a.m. to 2^h36^m p.m.	87	84	72	74	[2]73	[2]75	....	77
Dec. 14	11 02 a.m. to 4 02 p.m.	....	....	[2]82	[2]71	[2]81	[2]68	[2]68	[2]74
Dec. 18	9 15 a.m. to 3 15 p.m.	85	82	68	81	79	79	....	79
Dec. 22	8 40 a.m. to 2 40 p.m.	[2]68	[2]69	[2]70	[2]70	[2]71	[2]70	....	[2]70
Dec. 29	10 00 a.m. to 4 00 p.m.	....	[2]80	[2]76	[2]78	[2]75	[2]64	[2]71	[2]74
1909.									
Jan. 6	8 50 a.m. to 2 50 p.m.	87	85	80	82	85	71	....	82
Jan. 11	9 06 a.m. to 3 06 p.m.	....	78	77	70	76	71	....	74
Apr. 8	10 24 a.m. to 1 24 p.m.	....	[2]78	[2]78	[2]80	....	....	....	[2]79
1910.									
Jan. 31	9 30 a.m. to 11 30 a.m.	[2]82	[2]79	....	....	....	....	....	[2]81
Feb. 2	8 51 a.m. to 10 51 a.m.	[2]77	[2]78	....	....	....	....	....	[2]78
Feb. 8	9 38 a.m. to 11 38 a.m.	[2]83	[2]81	....	....	....	....	....	[2]82
Feb. 19	9 03 a.m. to 11 03 a.m.	[2]76	[2]82	....	....	....	....	....	[2]79
	Average	81	80	75	76	77	71	70	77

[1]The beginning of the "First hour" was for this subject approximately between 8^h30^m a. m. and 9^h30^m a. m.
[2]Heat eliminated corrected for change in body-weight, but not for change in body-temperature.

With the subject F. M. M., a larger number of prolonged experiments were made, many of them continuing for 6 hours. The results are given in table 30. An examination of the averages indicates again a remarkable uniformity both from hour to hour and from day to day. Individual variations, however, should not be lost sight of, as they show that it is always possible to obtain both large and abnormally small values. Strictly speaking, if the lowest value is accurately measured, that alone should be regarded as the absolute basal metabolism. The general picture of the basal metabolism is, however, not unlike that reported in the earlier observations by us,[1] and leads us to the general conclusion that the average carbon-dioxide production per hour is independent of the time of day and does not vary, at least with this subject, inside of a period of about 14 months. Somewhat wider fluctuations appear in the individual periods for the oxygen consumption and yet the average values are remarkably constant. As with J. R., the variations in the values for the heat production in the individual periods are considerable. While the average values do not show so close an agreement as do those for the carbon-dioxide production and the oxygen consumption, yet they indicate that this man produced 77 calories per hour in the chair calorimeter. It should be stated that this subject was somewhat unsatisfactory in that it was difficult for him to remain perfectly quiet. Probably the lowest measurements of the metabolism here do not indicate the basal metabolism of this man, as he was in the sitting position, but they do represent the minimum amount of extraneous muscular activity. For purposes of comparison with the values obtained for the metabolism after food, however, their use is justified, as the two series of determinations were made under like conditions.

An extended series of measurements of the basal metabolism, most of them of only 2 hours' duration, was made with J. J. C. Both the chair calorimeter and the bed calorimeter were used in this series. This man was also a very unsatisfactory subject, owing to his tendency to fall asleep, the degree of muscular repose thus being very irregular. Even with this subject the average values remain remarkably constant, especially for the carbon-dioxide production. It should be borne in mind, however, that the values from the third to the fifth periods are represented by only a single experiment. The measurements of the heat output for this man were extremely unsatisfactory, as no measurements of the body-temperature were obtained; hence the determinations for the heat have not been corrected for changes in this factor. By reference to table 31 it is seen that on the average this subject produced in the chair calorimeter 78 calories per hour, a rather remarkable agreement with the subjects J. R. and F. M. M.

[1] Benedict and Carpenter, Carnegie Inst. Wash. Pub. No. 126, 1910, pp. 171, 184, and 194, tables 69, 73, and 77.

TABLE 31.—*Basal metabolism of J. J. C. at different times of day in chair-calorimeter experiments.—Boston.* (Values per hour.)

Date.	Observation and duration.	First hour.[1]	Second hour.	Third hour.	Fourth hour.	Fifth hour.	Average.
1909.	*Carbon dioxide.*	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*
Apr. 7	10h56ma.m. to 1h56mp.m.	....	....	26.0	25.0	25.5	25.5
1910.							
Mar. 4	9 07 a.m. to 11 07 a.m.	25.5	26.5	....	....	....	26.0
Mar. 12	9 30 a.m. to 11 30 a.m.	23.5	24.5	....	....	....	24.0
Mar. 22	9 21 a.m. to 11 21 a.m.	26.5	23.5	....	....	....	25.0
Mar. 25	8 14 a.m. to 10 14 a.m.	26.0	24.5	....	....	....	25.5
Apr. 29	8 59 a.m. to 10 59 a.m.	27.0	25.5	....	....	....	26.0
May 9	9 31 a.m. to 11 31 a.m.	25.5	23.5	....	....	....	24.5
May 12	9 02 a.m. to 11 02 a.m.	26.5	24.0	....	....	....	25.0
May 18	8 56 a.m. to 10 56 a.m.	24.0	22.5	....	....	....	23.0
May 31	9 15 a.m. to 11 15 a.m.	25.5	26.0	....	....	....	26.0
1911.							
Jan. 10	9 08 a.m. to 11 23 a.m.	[2]27.0	[2]27.0	[2]25.0	....	....	26.0
Jan. 13	8 56 a.m. to 10 26 a.m.	[2]26.5	[2]27.5	....	....	....	27.0
Jan. 17	9 24 a.m. to 11 42 a.m.	[2]25.5	[2]27.5	[2]25.5	....	....	26.0
	Average	26.0	25.0	25.5	25.0	25.5	25.5
1909.	*Oxygen.*						
Apr. 7	10h56ma.m. to 1h56mp.m.	....	....	20.5	20.5	23.0	21.5
1910.							
Mar. 4	9 07 a.m. to 11 07 a.m.	21.0	23.0	....	....	....	22.0
Mar. 12	9 30 a.m. to 11 30 a.m.	20.5	20.5	....	....	....	20.5
Mar. 22	9 21 a.m. to 11 21 a.m.	24.0	21.0	....	....	....	22.5
Mar. 25	8 14 a.m. to 10 14 a.m.	21.5	20.5	....	....	....	21.0
Apr. 29	8 59 a.m. to 10 59 a.m.	24.0	20.5	....	....	....	22.0
May 9	9 31 a.m. to 11 31 a.m.	24.5	18.5	....	....	....	21.5
May 12	9 02 a.m. to 11 02 a.m.	21.0	18.5	....	....	....	20.0
May 18	8 56 a.m. to 10 56 a.m.	17.5	20.5	....	....	....	19.0
May 31	9 15 a.m. to 11 15 a.m.	21.0	19.5	....	....	....	20.5
1911.							
Jan. 10	9 08 a.m. to 11 23 a.m.	[2]22.0	[2]24.5	[2]21.0	....	....	22.5
Jan. 13	8 56 a.m. to 9 41 a.m.	[2]22.5	....	....	....	....	22.5
Jan. 17	9 24 a.m. to 11 42 a.m.	[2]24.5	....	[2]23.0	....	....	24.0
	Average	22.0	20.5	21.5	20.5	23.0	21.5
1910.	*Heat.*	*cals.*	*cals.*	*cals.*	*cals.*	*cals.*	*cals.*
Mar. 12	9h30ma.m. to 11h30ma.m.	71	79	....	....	....	75
Mar. 22	9 21 a.m. to 11 21 a.m.	[3]86	[3]80	....	....	....	[3]83
Mar. 25	8 14 a.m. to 10 14 a.m.	[3]80	[3]79	....	....	....	[3]79
Apr. 29	8 59 a.m. to 10 59 a.m.	74	78	....	....	....	76
May 12	9 02 a.m. to 11 02 a.m.	[3]83	[3]75	....	....	....	[3]79
May 18	8 56 a.m. to 10 56 a.m.	73	74	....	....	....	74
May 31	9 15 a.m. to 11 15 a.m.	82	75	....	....	....	79
1911.							
Jan. 10	9 08 a.m. to 11 23 a.m.	[2]77	[2]80	[2]77	....	....	[3]78
Jan. 13	8 56 a.m. to 10 26 a.m.	[2]78	[2]71	....	....	....	[3]75
	Average	78	77	77	....	....	78

[1]The beginning of the "First hour" with the chair calorimeter was approximately between 8h15m a. m. and 9h30m a. m.

[2]Calculated to hour basis; measured in period of 45 minutes. The heat values on Jan. 10 and 13, 1911, are heat eliminated corrected for change in body-weight, but not for change in body-temperature.

[3]Heat eliminated corrected for change in body-weight, but not for change in body-temperature.

TABLE 31 (continued).—*Basal metabolism of J. J. C. at different times of day in bed-calorimeter experiments.—Boston.* (Values per hour.)

Date.	Observation and duration.	First hour.[1]	Second hour.	Third hour.	Fourth hour.	Fifth hour.	Sixth hour.	Average.
1910.	*Carbon dioxide.*	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*
Oct. 27	9h08m a.m. to 12h08m p.m.	22.5	22.0	23.0	....	....	....	22.5
Oct. 31	9 22 a.m. to 12 22 p.m.	23.5	23.0	22.5	....	....	....	23.0
Nov. 3	9 35 a.m. to 11 35 a.m.	22.5	22.0	....	....	....	....	22.5
Nov. 8	9 46 a.m. to 12 18 p.m.	....	[2]22.0	22.0	....	....	....	22.0
Nov. 10	12 53 p.m. to 2 53 p.m.	....	....	....	....	22.0	23.0	22.5
Nov. 15	12 34 p.m. to 3 50 p.m.	....	....	....	[3]22.5	22.5	[3]22.0	22.5
	Average	23.0	22.5	22.5	22.5	22.5	22.5	22.5
	Oxygen.							
Oct. 27	9h08m a.m. to 12h08m p.m.	20.5	18.5	19.0	....	....	....	19.5
Oct. 31	9 22 a.m. to 12 22 p.m.	18.5	19.0	17.5	....	....	....	18.5
Nov. 3	9 35 a.m. to 11 35 a.m.	19.5	18.5	....	....	....	....	19.0
Nov. 8	9 46 a.m. to 12 18 p.m.	....	[2]17.5	18.5	....	....	....	18.0
Nov. 10	12 53 p.m. to 2 53 p.m.	....	....	....	....	19.0	19.0	19.0
Nov. 15	12 34 p.m. to 3 50 p.m.	....	....	....	....	19.5	[3]19.0	19.5
	Average	19.5	18.5	18.5	....	19.5	19.0	19.0
	Heat.	*cals.*	*cals.*	*cals.*	*cals.*	*cals.*	*cals.*	*cals.*
Oct. 27	9h08m a.m. to 12h08m p.m.	[4]68	[4]68	[4]67	....	....	....	[4]68
Oct. 31	9 22 a.m. to 12 22 p.m.	[4]59	[4]62	[4]63	....	....	....	[4]61
Nov. 3	9 35 a.m. to 11 35 a.m.	[4]66	[4]65	....	....	....	....	[4]66
Nov. 8	9 46 a.m. to 12 18 p.m.	....	[2]64	[4]64	....	....	....	[4]64
Nov. 10	12 53 p.m. to 2 53 p.m.	....	....	....	....	[4]65	[4]67	[4]66
Nov. 15	12 34 p.m. to 3 50 p.m.	....	....	....	[3]65	[4]65	[3]68	[4]66
	Average	[4]64	[4]65	[4]65	[4]65	[4]65	[4]68	[4]65

[1]The beginning of the "First hour" with the bed calorimeter was approximately between 9 a. m. and 9h30m a. m.

[2]Calculated to hour basis; measured in period of 1h32m. Heat not corrected for change in body-temperature.

[3]Calculated to hour basis; measured in period of 1h8m. Heat not corrected for change in body-temperature.

[4]Heat eliminated corrected for change in body-weight, but not for change in body-temperature.

The bed-calorimeter experiments with J. J. C. were even more unsatisfactory than those with the chair calorimeter, as the subject showed a decided tendency to go to sleep and at times a definite although not extended activity. Under these conditions the metabolism was measurably less than the values obtained with the chair calorimeter. The carbon-dioxide production from hour to hour was remarkably uniform, especially when the average values alone are considered. Aside from the values for the first period the heat measurements again show constant average values; the general average for this apparatus was 65 calories per hour, a value some 13 calories less than that found with the chair calorimeter. This value undoubtedly represents very closely the basal metabolism of J. J. C., although, as stated above, even the values obtained with the chair calorimeter may justifiably be used as a baseline for studying the influence of the ingestion of food in experiments

made with the same apparatus. Both basal values find their subsequent use in a consideration of the results of the food experiments.

The series of experiments with L. E. E., in which only the chair calorimeter was used, extended over a relatively short period of time—*i. e.*, from March 14 to May 11, 1910. (See table 32.) The average values for both the carbon-dioxide production and the oxygen consumption agree very well with those found with the subjects previously considered. Those for the heat production show a striking disagreement with each other, the high value of 81 calories being found for the first hour, while a low value of 68 calories is found in the third hour of one experiment. It is probable that these variations in the values for heat output are due to the fact that they have not been corrected for changes in body-temperature, as these measurements were not made; hence the heat values correspond to heat elimination rather than to heat production.

TABLE 32.—*Basal metabolism of L. E. E. at different times of day in chair-calorimeter experiments.—Boston.* (Values per hour.)

Date.	Observation and duration.	First hour.[1]	Second hour.	Third hour.	Average.
1910.	*Carbon dioxide.*	*gm.*	*gm.*	*gm.*	*gm.*
Mar. 14	9h23ma.m. to 11h23ma.m.	....	28.5	25.5	27.0
May 3	8 40 a.m. to 10 40 a.m.	25.0	24.5	....	25.0
May 11	8 31 a.m. to 10 31 a.m.	25.0	24.0	....	24.5
	Average.	25.0	25.5	25.5	25.5
	Oxygen.				
Mar. 14	9h23ma.m. to 11h23ma.m.	....	23.0	21.5	22.0
May 3	8 40 a.m. to 10 40 a.m.	22.0	21.0	....	21.5
May 11	8 31 a.m. to 10 31 a.m.	22.0	21.5	....	21.5
	Average.	22.0	22.0	21.5	21.5
	Heat.	*cals.*	*cals.*	*cals.*	*cals.*
Mar. 14	9h23ma.m. to 11h23ma.m.	....	[2]72	[2]68	[2]70
May 3	8 40 a.m. to 10 40 a.m.	[2]81	[2]74	....	[2]78
May 11	8 31 a.m. to 10 31 a.m.	[2]81	[2]79	....	[2]80
	Average.	[2]81	[2]75	[2]68	[2]76

[1]The beginning of the "First hour" was for this subject approximately between 8h30m a. m. and 9h30m a. m.

[2]Heat eliminated corrected for change in body-weight, but not for change in body-temperature.

Another subject, V. G., who was measured in both the chair calorimeter and the bed calorimeter, was not temperamentally adapted for experimentation with such a fine point at issue as the influence of the ingestion of food. The basal values obtained with the chair calorimeter show larger variations from hour to hour than have thus far been noted with any of the subjects; indeed, the measurements of the heat output were lost in the experiment of January 21. (See table 33.) Measure-

TABLE 33.—*Basal metabolism of V. G. at different times of day in calorimeter experiments.—Boston.* (Values per hour.)

Date.	Observation and duration.	First hour.[1]	Second hour.	Third hour.	Fourth hour.	Average.
	CHAIR CALORIMETER.	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*
1911.	*Carbon dioxide.*					
Jan. 2	9^h07^m a.m. to 9^h52^m a.m. and 11 22 a.m. to 12 15 p.m.	[2]30.0	....	....	30.0	30.0
Jan. 21	8 55 a.m. to 10 25 a.m.	[2]28.5	[2]29.5	....	....	29.0
	Average	29.5	29.5	....	30.0	29.5
	Oxygen.					
Jan. 2	9^h07^m a.m. to 9^h52^m a.m. and 11 22 a.m. to 12 15 p.m.	[2]24.0	....	....	26.0	25.0
Jan. 21	8 55 a.m. to 10 25 a.m.	[2]22.0	[2]28.5	....	....	25.5
	Average	23.0	28.5	....	26.0	25.5
	Heat.	*cals.*	*cals.*	*cals.*	*cals.*	*cals.*
Jan. 2	9^h07^m a.m. to 9^h52^m a.m. and 11 22 a.m. to 12 15 p.m.	[2]86	....	....	[3]79	[3]83
	BED CALORIMETER.					
1910.	*Carbon dioxide.*	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*
Oct. 24	9^h39^m a.m. to 12^h39^m p.m.	....	23.0	24.5	24.0	24.0
Oct. 26	9 52 a.m. to 12 52 p.m.	....	[4]24.5	[4]24.0	....	24.5
Nov. 4	9 26 a.m. to 11 56 a.m.	....	[4]23.5	24.0	....	24.0
Nov. 7	9 01 a.m. to 11 06 a.m.	24.0	25.0	....	....	24.5
Dec. 19	9 12 a.m. to 11 27 a.m.	[2]26.5	[2]24.5	[2]26.0	....	25.5
	Average	25.5	24.0	24.5	24.0	24.5
	Oxygen.					
Oct. 24	9^h39^m a.m. to 12^h39^m p.m.	....	20.0	22.5	21.0	21.0
Oct. 26	9 52 a.m. to 12 52 p.m.	....	[4]19.0	[4]20.0	....	19.5
Nov. 4	9 26 a.m. to 11 56 a.m.	....	[4]20.5	20.5	....	20.5
Nov. 7	9 01 a.m. to 11 06 a.m.	19.0	19.0	....	....	19.0
Dec. 19	9 12 a.m. to 11 27 a.m.	[2]20.5	[2]23.0	[2]22.5	....	22.0
	Average	20.0	20.5	21.5	21.0	20.5
	Heat.	*cals.*	*cals.*	*cals.*	*cals.*	*cals.*
Oct. 24	9^h39^m a.m. to 12^h39^m p.m.	....	[3]61	[3]69	[3]68	[3]66
Oct. 26	9 52 a.m. to 12 52 p.m.	....	[4]66	[4]67	....	[3]67
Nov. 4	9 26 a.m. to 11 56 a.m.	....	[4]65	[3]68	....	[3]67
Nov. 7	9 01 a.m. to 11 06 a.m.	[3]64	[3]64	....	....	[3]64
Dec. 19	9 12 a.m. to 11 27 a.m.	....	[2]65	[2]68	....	[3]67
	Average	[3]64	[3]64	[3]68	[3]68	[3]66

[1]The beginning of the "First hour" for this subject was approximately between 9 a. m. and 9^h15^m a. m.

[2]Calculated to hour basis; measured in period of 45 minutes. The heat values are heat eliminated corrected for change in body-weight, but not for change in body-temperature.

[3]Heat eliminated corrected for change in body-weight, but not for change in body-temperature.

[4]Calculated to hour basis; measured in period of 1½ hours. Heat not corrected for change in body-temperature.

ments of the body-temperature were practically impossible with this subject and hence the use of the heat values for comparison with those obtained after food is questionable. The average results of the bed-calorimeter experiments show no great fluctuation, even for the heat output. With this subject, also, the average values found with the chair calorimeter are perceptibly higher than those found with the bed calorimeter.

The subject T. M. C., thoroughly aware of the importance of uniform muscular activity, gives us values in chair-calorimeter experiments that are probably as accurate and consistent as can be expected with any subject. (See table 34.) They show but few deviations from the normal value for both the carbon-dioxide production and the oxygen consumption. As no measurements of the body-temperature were made, the usual variations in the measurements of the heat output appear. The average results show a remarkable constancy in the metabolism from hour to hour. The period of experimentation was short, being only from January 3 to January 12, 1911, and no marked differences are found from day to day. The low metabolism noted in the whole series is in large part explained by the small body-weight of the subject.

Four other subjects, A. G. E., C. H. H., Dr. H., and D. J. M., were studied in the chair calorimeter for two 1-hour periods; the results of these few experiments are also given in table 34. As a rule, the values obtained show the usual uniformity from hour to hour.

TABLE 34.—*Basal metabolism at different times of day in chair-calorimeter experiments.—Boston.* (Values per hour.)[1]

Subject and observation.	Date.	Duration.	First hour.[2]	Second hour.	Third hour.	Fourth hour.	Average.
T. M. C.	1911.		*gm.*	*gm.*	*gm.*	*gm.*	*gm.*
Carbon dioxide.	Jan. 3	8h25m a.m. to 9h58m a.m.	19.0	19.0	....	....	19.0
	Jan. 7	8 43 a.m. to 10 15 a.m. 11 45 a.m. to 12 30 p.m.	19.0	18.5	....	18.0	18.5
	Jan. 12	8 55 a.m. to 10 25 a.m.	19.5	18.5	....	....	19.0
		Average	19.0	18.5	....	18.0	19.0
Oxygen	Jan. 3	8h25m a.m. to 9h58m a.m.	17.5	18.0	....	....	18.0
	Jan. 7	8 43 a.m. to 10 15 a.m. 11 45 a.m. to 12 30 p.m.	16.5	17.0	....	17.0	17.0
	Jan. 12	8 55 a.m. to 10 25 a.m.	16.5	17.5	....	....	17.0
		Average	17.0	17.5	....	17.0	17.5
			cals.	*cals.*	*cals.*	*cals.*	*cals.*
Heat	Jan. 3	8h25m a.m. to 9h58m a.m.	[3]66	[3]60	....	....	[3]63
	Jan. 7	8 43 a.m. to 10 15 a.m. 11 45 a.m. to 12 30 p.m.	[3]56	[3]55	....	[3]56	[3]56
	Jan. 12	8 55 a.m. to 10 25 a.m.	[3]66	[3]58	....	....	[3]62
		Average	[3]63	[3]58	....	[3]56	[3]60

[1]Values for T. M. C. calculated to hour basis; measured in periods of 45 minutes.
[2]The beginning of the "First hour" was approximately between 8h30m a. m. and 9 a. m.
[3]Heat eliminated corrected for change in body-weight but not for change in body-temperature.

TABLE 34. (continued).—*Basal metabolism at different times of day in chair-calorimeter experiments.—Boston.* (Values per hour).

Subject and observation.	Date.	Duration.	First hour.[1]	Second hour.	Third hour	Fourth hour.	Average.
A. G. E.	1911.		*gm.*	*gm.*	*gm.*	*gm.*	*gm.*
Carbon dioxide	Jan. 23	8h47ma.m. to 10h17ma.m...	[2]24.5	[2]24.0	....	....	24.5
Oxygen.....	Jan. 23	8 47 a.m. to 10 17 a.m...	[2]22.0	[2]21.0	....	....	21.5
			cals.	*cals.*	*cals.*	*cals.*	*cals.*
Heat.....	Jan. 23	8 47 a.m. to 10 17 a.m...	[2]72	[2]71	....	....	[3]72
C. H. H.			*gm.*	*gm.*	*gm.*	*gm.*	*gm.*
Carbon dioxide	Jan. 18	8h58ma.m. to 10h28ma.m...	[2]22.0	[2]22.0	....	....	22.0
Oxygen	Jan. 18	8 58 a.m. to 10 28 a.m...	[2]20.0	[2]19.5	....	....	20.0
			cals.	*cals.*	*cals.*	*cals.*	*cals.*
Heat.....	Jan. 18	8 58 a.m. to 10 28 a.m...	[2]60	[2]60	....	....	[3]60
DR. H.[4]	1910.		*gm.*	*gm.*	*gm.*	*gm.*	*gm.*
Carbon dioxide	Feb. 14	9h24ma.m. to 11h24ma.m...	....	23.0	21.5	....	22.0
	Feb. 17	9 31 a.m. to 11 31 a.m...	....	21.5	21.5	....	21.5
		Average.....	....	22.0	21.5	....	22.0
Oxygen.....	Feb. 14	9h24ma.m. to 11h24ma.m...	....	20.5	19.5	....	20.0
	Feb. 17	9 31 a.m. to 11 31 a.m...	....	20.0	20.5	....	20.5
		Average.....	....	20.5	20.0	....	20.5
D. J. M.			*gm.*	*gm.*	*gm.*	*gm.*	*gm.*
Carbon dioxide	Mar. 23	9h33ma.m. to 11h33ma.m...	....	25.5	25 5	....	25.5
	June 3	9 37 a.m. to 11 37 a.m...	....	25.5	24.5	....	25.0
	June 7	9 21 a.m. to 11 21 a.m...	....	25.5	26.0	....	26.0
		Average.....	....	25.5	25.5	....	25.5
Oxygen.....	Mar. 23	9h33ma.m. to 11h33ma.m...	....	20.5	22.0	....	21.0
	June 3	9 37 a.m. to 11 37 a.m...	.....	20.5	20.5	....	20.5
	June 7	9 21 a.m. to 11 21 a.m...	....	21.5	20.5	....	21.0
		Average.....	....	21.0	21.0	....	21.0
				cals.	*cals.*	*cals.*	*cals.*
Heat.....	Mar. 23	9h33ma.m. to 11h33ma.m...	....	[3]68	[3]72	....	[3]70
	June 3	9 37 a.m. to 11 37 a.m...	....	76	76	....	76
	June 7	9 21 a.m. to 11 21 a.m...	....	[3]82	[3]78	....	[3]80
		Average.....	....	75	75	....	75

[1]The beginning of the "First hour" was for the subjects in this table approximately between 8h30m a. m. and 9 a. m.

[2]Calculated to hour basis; measured in period of 45 min. The heat values for subjects A. G. E., and C. H. H., are heat eliminated corrected for change in body-weight, but not for change in body-temperature.

[3]Heat eliminated corrected for change in body-weight, but not for change in body-temperature.

[4]The heat measurements for the experiments with this subject were technically defective.

A summary of the values for the basal metabolism found with the subjects of the Boston calorimeter experiments is given in table 35. With two subjects we have values obtained with both the chair and bed calorimeters, which show that the metabolism in the chair calorimeter is perceptibly higher than that in the bed calorimeter. The difference is so much greater than that which would commonly be expected, and also greater than that shown in an earlier report from

this laboratory,[1] that it must be considered as due not merely to a difference in body position but also to an admittedly somewhat more liberal muscular activity in the chair calorimeter as compared with that in the bed calorimeter. Undue stress must not be laid upon the rather remarkable agreement in the values for the heat output with the subjects J. R., F. M. M., L. E. E., D. J. M., and J. J. C., in the experiments with the chair calorimeter or upon the extraordinarily low values obtained with C. H. H. and A. G. E., for the fact that the body-temperature measurements were lacking in many of the experiments plays an mportant rôle in the interpretation of these values.

TABLE 35.—*Summary of average values for basal metabolism determined for subjects in calorimeter experiments.—Boston.* (Amounts per hour.)

Subject.	Calorimeter.	Average body-weight without clothing.	Carbon dioxide.	Oxygen.	Heat.	Nitrogen[1] excreted in urine.
		kilos.	*grams.*	*grams.*	*cals.*	*grams.*
J. R.	Chair	68.3	27.0	23.0	77	0.46
F. M. M.	Chair	60.2	25.5	22.5	77	.43
J. J. C.	Chair	64.8	25.5	21.5	78	.40
	Bed	63.5	22.5	19.0	[2]65	
L. E. E.	Chair	59.5	25.5	21.5	[2]76	.52
V. G.	Chair	55.8	29.5	25.5	[2]83	.35
	Bed	53.3	24.5	20.5	[2]66	
T. M. C.	Chair	47.7	19.0	17.5	[2]60	.41
A. G. E.	Chair	56.4	24.5	21.5	[2]72	.42
C. H. H.	Chair	54.8	22.0	20.0	[2]60	[3].36
DR. H.	Chair	66.3	22.0	20.5	..	.32
D. J. M.	Chair	58.1	25.5	21.0	75	.51

[1]Includes all nitrogen obtained with these subjects for the periods in which the basal metabolism was determined and during any other periods without food. (See table 36.)
[2]Heat eliminated corrected for change in body-weight, but not for change in body-temperature.
[3]Subject was without food in first 3 hours of the 5 hours covered by each sample included in this average. Sucrose was given at the end of 3 hours.

For the purpose of indicating the protein metabolism of these Boston subjects, we have included in table 35 average values for the nitrogen excretion per hour, not only for the calorimeter experiments, but for other experiments not included in this publication. The values from which these averages are drawn are given in table 36. No marked variation is found with the different individuals, the same subject usually having approximately the same nitrogen excretion per hour under the conditions of measurement employed. It is rarely that such contrasts are noted as that in the results for V. G., with whom a very small excretion of nitrogen occurs on November 21, while 3 days earlier almost the maximum amount is found. That this corresponds to an actual difference in the protein katabolism is by no means definitely assured from these figures, for the difficulty of completely emptying the bladder, especially in the case of young and untrained subjects, is well known to practiced experimenters.

[1]Emmes and Riche, Am. Journ. Physiol., 1911, **27**, p. 406.

TABLE 36.—*Nitrogen excreted in urine during experiments without food.* (Amounts per hour.)

Subject and date.	Amount.	Subject and date.	Amount.	Subject and date.	Amount.
1908.	*gram.*	1910.	*gram.*	1911.	*gram.*
J. R. Dec. 3...	0.37	L. E. E. Mar. 7	0.49	J. J. C. Jan. 13	0.50
Dec. 17...	.46	(con.) Mar. 14	.56	Jan. 17	.43
1909.		Mar. 19	.52	Jan. 30	.50
Feb. 25...	.46	Mar. 29	.73	Feb. 1	.28
Mar. 20...	.45	May 3	.51	Apr. 25	.33
Apr. 27...	.46	June 7	.52		
Apr. 29...	.46	June 11	.66	Average	.40
May 1...	.49	July 1	.49		
May 6...	.38	Nov. 26	.44	1910.	
May 12...	.55	Nov. 29	.57	V. G. Oct. 24	0.46
May 15...	.47	Dec. 3	.45	Oct. 26	.32
May 18...	.49	Dec. 9	.46	Nov. 4	.32
May 21...	.45			Nov. 7	.25
May 29...	.55	Average	.52	Nov. 18	.49
1910.				Nov. 21	.18
May 5...	.44	1909.		Dec. 19	.32
May 10...	.44	J. J. C. Jan. 27	0.42	1911.	
		(con.) Feb. 2	.29	Jan. 2	.52
Average...	.46	Mar. 3	.63	Jan. 5	.32
		Mar. 5	.38	Jan. 21	.27
1908.		Mar. 6	.40	Feb. 6	.28
F. M. M. Dec. 9...	0.44	Mar. 16	.40	Feb. 15	.41
Dec. 14...	.53	Apr. 7	.38	Mar. 11	.37
Dec. 18...	.37	1910.			
Dec. 22...	.35	Feb. 5	.38	Average	.35
Dec. 29...	.28	Feb. 15	.24		
1909.		Feb. 18	.37	1909.	
Jan. 6....	.33	Feb. 24	.42	T. M. C. Feb. 4	0.53
Jan. 11....	.36	Mar. 4	.47	Mar. 23	.49
Jan. 12....	.46	Mar. 15	.41	1910.	
Jan. 22....	.53	Mar. 18	.45	Feb. 7	.39
Feb. 24....	.46	Mar. 22	.23	Feb. 23	.44
Apr. 8....	.39	Mar. 25	.41	Mar. 23	.55
1910.		Mar. 31	.31	Mar. 26	.45
Jan. 31....	.54	Apr. 4	.49	May 16	.40
Feb. 8....	.45	Apr. 7	.46	May 25	.32
Feb. 19....	.54	Apr. 29	.40	June 2	.44
		May 6	.38	June 8	.49
Average...	.43	May 9	.26	June 20	.35
		May 12	.34	June 24	.40
1909.		June 6	.48	July 12	.39
L. E. E. Jan. 8....	0.50	June 8	.47	Nov. 14	.36
Apr. 28....	.62	June 10	.50	Nov. 16	.45
Apr. 30...	.46	June 13	.57	1911.	
May 3...	.45	Oct. 27	.45	Jan. 3	.36
May 7...	.47	Oct. 31	.47	Jan. 7	.25
May 10...	.48	Nov. 3	.37	Jan. 12	.28
May 13...	.39	Nov. 5	.31		
May 20...	.52	Nov. 8	.32	Average	.41
May 22...	.54	Nov. 10	.30		
June 1...	.53	Nov. 15	.41	1910.	
June 9...	.66	Nov. 22	.38	A. G. E. Mar. 24	0.35
June 16...	.48	1911.		Mar. 28	.45
Oct. 16....	.42	Jan. 10	.59	Apr. 2	.43
				Apr. 6	.43

TABLE 36 (continued).—*Nitrogen excreted in urine during experiments without food.* (Amounts per hour.)

Subject and date.	Amount	Subject and date.	Amount	Subject and date.	Amount
1910.	*gram.*	1911.	*gram.*	1910.	*gram.*
A. G. E. Apr. 9...	0.41	C. H. H. May 10	[1]0.34	D. J. M. Mar. 21	0.59
(con.) May 19...	.43	May 23	[1].38	Mar. 23	.55
May 27...	.45			Mar. 25	.47
May 31...	.47	Average	[1].36	Mar. 30	.32
June 3...	.49			Apr. 8	.70
June 13...	.47	1910.		June 3	.49
July 2...	.33	DR. H. Feb. 14	0.33	June 7	.45
1911.		Feb. 17	.30		
Jan. 23...	.28			Average	.51
		Average	.32		
Average...	.42				

[1]Subject was without food in first 3 hours of the 5 hours covered by the sample in each case. Sucrose was given at the end of 3 hours.

GENERAL CONCLUSIONS REGARDING 8-HOUR EXPERIMENTS IN BOSTON.

With the shortening of the experimental period, the distinction between heat production and heat elimination becomes of considerable consequence. In the 24-hour experiments it was found that the heat production and heat elimination were essentially identical—that is, that the body-temperature as determined by rectal measurements was practically the same each morning at 7 o'clock when the experimental day ended. While the correctness of this assumption as a generalization may fairly be questioned, nevertheless very considerable differences in body-temperature may actually appear and yet not affect the calculation of the total heat production when based on the 24-hour unit. With short periods, on the other hand, temperature fluctuations may normally be expected. It has been demonstrated that there are ordinarily variations of 1° to 2° C. in the normal rectal temperature, the minimum appearing from 3 to 5 a. m., and the maximum in the late afternoon. Even during short periods of rest there may be considerable fluctuation in the body-temperature. Consequently, as the experimental period is shortened, there is an increasing danger of possible error in the measurements of the heat production owing to either a storage of heat in the body, as shown by an increase in the body-temperature, or a loss of heat, as indicated by a fall in the body-temperature. To obtain the true heat production, the values for this storage or loss should be added to or deducted from the values obtained for the heat actually eliminated during the period.

This question is of special significance when the attempt is made to compare the heat production and the gaseous exchange—in other words, to compare the direct and indirect calorimetry—the difficulties lying for the most part in securing a proper measurement of the body-

temperature. Many inconsistencies that appear at first sight in the results of these experiments, as, for instance, those with L. E. E. (table 32), may properly be ascribed to erroneous measurements of the body-temperature or to the lack of such measurements.

At about the time these experiments were made special attention was devoted to the measurement of heat production and the description of a special apparatus for measuring the body-temperature deep in the rectum was published.[1] It has been impracticable in all subsequent researches to take advantage of this method of measurement, and yet experience in this laboratory, as well as elsewhere, has shown that heat elimination as measured by the respiration calorimeter can have but little significance without a definite knowledge of the very considerable change in the body-temperature that may accompany a normal or physiological experiment and is quite likely to accompany observations on pathological cases.

If we make a general study of the metabolism data obtained in these Boston experiments, the results may be summed up as follows: As a rule, the average values for the gaseous metabolism for each subject show uniformity, although at times there is more or less variation in the individual values. Owing, probably, to the fact that the body-temperature measurements were lacking or defective, there is frequently considerable variation in the heat output, although even here the values do not lack uniformity in some cases. With the two subjects who were studied in both the chair calorimeter and the bed calorimeter, lower values were invariably found with the bed calorimeter, this being due to the greater degree of muscular repose.

It should be noted that the criterion for uniformity is a plus or minus variation of 5 per cent—that is, if the values for the carbon dioxide or the oxygen are within 1 gram of each other on the 20 to 25 gram basis, they are considered reasonably uniform. Hence we must admit at the outset the possibility of variations in the individual periods of at least plus or minus 5 per cent. This is important to note in any subsequent use of these values in determining the influence of the ingestion of food, for frequently the effect of the ingestion of food may be not much outside this limit. Accordingly this basis of experimentation for food experiments, while favorable when a large effect of digestion is to be expected, is still of doubtful value when the subtler effects are studied, as they may be entirely lost sight of.

We see no reason, however, why the results of these experiments should not, with intelligent appreciation of their defects, still be used for comparison with the results of experiments made under identically the same experimental conditions after the ingestion of food. One major criticism of so using these values may be made, in that while

[1]Benedict and Slack, Carnegie Inst. Wash. Pub. No. 155, 1911.

the temperature curve of the normal body may be reasonably uniform when no food is taken, it is quite likely that the ingestion of food may produce a somewhat rapid rise in temperature which, if not measured accurately, would still further vitiate the calculation of the values for the heat production. It is thus seen that it will be necessary to confine the major discussion of the influence of the ingestion of food upon metabolism to its effect upon the respiratory exchange and the indirect calorimetry computed therefrom, using the grosser heat measurements as subsidiary evidence.

SHORT-PERIOD EXPERIMENTS.

An examination of the literature (see pages 10 to 46) shows that many of the researches have been carried out with short periods ranging from 2 hours to 10 or 15 minutes; the majority of the experiments were made in 15-minute periods. In our study of the metabolism after food a large proportion of the basal metabolism experiments were likewise made with these short periods.

CRITIQUE OF THE SHORT-PERIOD METHOD.

This method is particularly adapted for experiments with a respiration apparatus with which the gaseous metabolism may be determined and the heat output computed from the results. Such experiments are carried out with considerably less expense and the use of intricate calorimetric apparatus is avoided. Furthermore, comparable values for the metabolism may be obtained on the same day; thus one may be certain of a specially determined and reliable base-line each day, with accurate determinations of body-temperature, pulse rate, and respiration rate.

With both the 24-hour period and the 8-hour period, various time-consuming observations must be made and much duplicate data secured before a satisfactory average is obtained. With the short-period base-line, values may be quickly obtained. Indeed, the results of one or two periods may be rejected on account of extraneous muscular activity of some definite nature, and a true base-line may be found from the average of the other periods with more constant results. To avoid possible activity in the rest periods, it has been the excellent custom in Johansson's laboratory in Stockholm to alternate the periods of complete rest with periods of moderate activity and not to insist upon the tedium of an arbitrarily imposed complete muscular rest for any great length of time.

After two or three periods without food have been obtained with closely agreeing results, and the constancy of the base-line established for that day, food may be given the subject and a series of observations made for from 1 to 6 hours, or even longer. With 15-minute periods

it is possible to make an observation practically every 30 minutes. The course of the metabolism after the taking of the food can thus be closely followed and a satisfactory curve obtained showing the immediate effect, the maximum increment, and the gradual cessation of the excess heat production. The short-period method is thus more especially fitted for studying small variations in metabolism and particularly the rapidly occurring and disappearing changes.

Although sufficient material is obtained by this method of measurement to draw a graphic picture of the metabolism, the conditions are still not ideal, as the measurements are not continuous and small variations and possible compensation may thus be lost, especially if the intervals between periods are lengthened from any cause.

This method of determining the metabolism for comparison purposes is further open to criticism in that the assumption must be made that the metabolism remains constant throughout the experimental day, whereas the results may be affected by a daily rhythm or variation. The question may be fairly asked: When no food is taken, is the metabolism the same at 3 p. m. as at 9 a. m.? In other words, if a base-line is determined at 9 a. m., food is given at 10 a. m., and the influence of the food is followed until 3 or 4 p. m., can it be assumed that the increment noted at 4 p. m. above the base-line found at 9 a. m. is due exclusively to the influence of food, or is it due in part to a daily rhythm? Johansson found in his experiments, which were carried out with precautions to maintain absolute muscular repose, that the time of day had but little or no influence upon the carbon-dioxide excretion.[1] In considering the results of our experiments made by the short-period method, this question of constancy in the basal metabolism from hour to hour may be discussed intelligently, for a large amount of data is available from which conclusions may be drawn.

DISCUSSION OF RESULTS OF SHORT-PERIOD EXPERIMENTS.

Aside from a few experiments in which the Tissot apparatus was used,[2] the universal respiration apparatus[3] was employed exclusively for the short-period experiments. The experiments usually began between 8 and 9 a. m. and continued until noon, and sometimes later; the periods as a rule varied but little from 15 minutes in length. In some instances the experiment was 18 periods in length, but the majority were from 5 to 6 periods long.

The data for all of the subjects with whom experiments of five or more periods have been made have been collected and tabulated; the

[1]Johansson, Skand. Arch. f. Physiol., 1898, **8**, p. 103. Magnus-Levy likewise states that the time of day has no influence upon the metabolism. (Magnus-Levy, Arch. f. d. ges. Physiol., 1894, **55**, p. 32.)

[2]Tissot, Journ. de physiol. et de pathol. gén., 1904, **6**, p. 688.

[3]Benedict, Am. Journ. Physiol., 1909, **24**, p. 345; Deutsch. Arch. f. klin. Med., 1912, **107**, p. 156. See, also, p. 202 of this monograph.

results obtained with over 30 subjects are thus available for comparison. With several subjects the experiments were made at intervals during a period of five or even six years, but with the majority they were made in a period of approximately two months or even two weeks. An abstract of similar data, which includes nearly all of the subjects with whom we are dealing in this publication, has been given in a previous paper from this laboratory.[1] Emphasis was there laid upon the variations in the average maximum values for the oxygen consumption, using the average minimum value for a basis. Inasmuch as it is important to note the actual variations which may be observed in a long series of experiments of this kind, the data will be considered in more detail in this publication.

As it would be impracticable to print all of the material obtained, three typical subjects have been selected and the carbon-dioxide production and oxygen consumption per minute for the individual periods with these subjects have been tabulated. The data for the other subjects are given in abstract. In the tables showing the detailed results, the day has been subdivided into half-hour periods and the data for the individual 15-minute periods of the experiment placed according to the time the observations were made. The values given under "first period" commonly represent those obtained in the experimental periods which occurred between 8 and 8^h30^m a. m. At the bottom of the tables are given the average values for each 30-minute period throughout the series, thus indicating the average course of the metabolism throughout the day. The minimum and the maximum values for each period are also given and the mean variations of the individual values from the averages. In the extreme right-hand column the averages for the individual experiments are placed, showing the course of the metabolism throughout the months or years of the study.

In studying the results given in these tables, emphasis should be laid only upon the average values and no particular significance given to single values like the maximum and minimum data. This is in accordance with the custom of this laboratory, as such values are liable to technical errors and physiological variations which must necessarily creep into experiments as complicated as these. The average values for the day are drawn from at least two results and usually three or more, while those for consecutive periods are computed from 5 to 42 periods. It should furthermore be remembered that the data for the oxygen consumption give a more logical basis for discussion than those obtained for the carbon-dioxide elimination. This is due to the remarkable influence upon the carbon-dioxide production of the character of the previous diet,[2] the large variations in the calorific equivalent of

[1]Benedict, Journ. Biol. Chem., 1915, **20,** p. 263, table 4.
[2]Benedict and Higgins, Am. Journ. Physiol., 1912, **30,** p. 217.

carbon dioxide with varying respiratory quotients, and the possibility of an over-ventilation of the lungs accompanied by an excessive carbon-dioxide production.

Experiments with H. L. H.

The most extensive series of experiments was obtained with Mr. H. L. Higgins, who was long connected with the experimental work of the Nutrition Laboratory. The first experiment with this subject was on May 23, 1910, and the last on June 2, 1915; although not made at regular intervals, the observations were reasonably well distributed over this period of about five years. Confining our discussion first to the carbon-dioxide values and considering the influence upon them of the time of day and their variation in the consecutive periods, we find that the carbon-dioxide production per minute shows considerable variation from hour to hour in the individual experiments. (See table 37.) Differences as large as 20 c.c. or more are occasionally noted, this corresponding to an approximate variation of 10 per cent. Thus in the experiment of September 24, 1911, there was a difference between the first and second periods of 26 c.c. and between the first and fourth periods of 31 c.c., or nearly 15 per cent of the average value for the day, while the values for January 13, 1912, show a difference between the second and third periods of 30 c.c., again about 15 per cent of the average for the day. The average values for the consecutive periods are remarkably constant. The highest is that for the first period, 203 c.c., drawn from 10 periods; the lowest is that for the fifth period, 195 c.c., drawn from 21 periods. Although the average value for the fifth period is lower than that for the first, we do not find here, as with some of the experiments made with the 8-hour method, any tendency towards a falling off or material alteration of the values as the day progresses.

The greatest mean variation, 11.3 c.c., occurs in the first period, this being slightly more than 5 per cent of the average value for this period. The mean variation of the averages for all the periods is but 7.8 c.c., an agreement that indicates uniform experimental conditions and accuracy in technique.

From the general picture of the carbon-dioxide production of this subject during the period of five years, which is obtained from the averages in the extreme right-hand column, we find that while there are individual variations there is no general tendency toward a material alteration in the metabolism; this is further confirmed by the small average mean variation. We may therefore infer that the carbon-dioxide production of this subject did not vary to any extent in the course of the five years of experimenting. The average carbon-dioxide production for H. L. H., as shown by the determinations made during this period, may be considered as 198 c.c. per minute.

TABLE 37.—*Carbon-dioxide produced at different times of day in respiration experiments; subject H. L. H., in post-absorptive condition and lying on couch.* (Values per minute.)

Average age, 25 years. Average body-weight (naked), 61.4 kilograms. Height, 172 cm.

Date.	Duration of experiment.	First half hour.[1]	Second half hour.[1]	Third half hour.[1]	Fourth half hour.[1]	Fifth half hour.[1]	Sixth half hour.[1]	Seventh half hour.[1]	Eighth half hour.[1]	Average.
1910		c.c.	c.c.	c.c.	c.c.	c.c.	c.c.	c.c.	c.c.	c.c.
May 23	8h30m a.m. to 11h05m a.m.	...	206	201	202	...	206	199	...	203
May 28	8 28 a.m. to 11 54 a.m.	...	198	194	190	205	206	206	195	199
June 1	8 35 a.m. to 12 01 p.m.	...	191	193	205	185	192	199	209	196
June 4	8 24 a.m. to 11 07 a.m.	...	193	203	193	192	193	202	...	196
June 9	8 30 a.m. to 11 57 a.m.	...	189	204	181	190	197	190	184	191
June 22	8 41 a.m. to 11 41 a.m.	...	...	190	180	181	189	197	193	188
July 16	8 45 a.m. to 11 19 a.m.	...	195	182	205	196	...	199	...	195
July 25	8 46 a.m. to 11 13 a.m.	...	188	197	182	202	194	208	...	195
1911.										
Mar. 25	8 30 a.m. to 9 40 a.m.	...	201	200	204	...	...	...	...	202
May 17	8 31 a.m. to 9 51 a.m.	...	188	189	195	...	...	...	...	191
May 24	8 40 a.m. to 10 39 a.m.	...	...	178	185	185	185	...	...	183
June 1	8 43 a.m. to 9 38 a.m.	...	...	197	197	...	...	...	...	197
June 7	8 51 a.m. to 9 39 a.m.	...	...	190	192	...	...	...	...	191
July 1	8 58 a.m. to 10 19 a.m.	...	...	185	194	198	...	...	...	192
Sept. 11	8 22 a.m. to 9 36 a.m.	...	212	207	211	...	...	...	...	210
Sept. 20	8 49 a.m. to 10 10 a.m.	...	...	189	207	221	...	...	...	206
Sept. 21	8 48 a.m. to 10 06 a.m.	...	...	210	204	210	...	...	...	208
Sept. 22	8 53 a.m. to 10 06 a.m.	...	...	196	201	199	...	...	...	199
Sept. 23	8 53 a.m. to 10 11 a.m.	...	...	196	195	195	...	...	...	195
Sept. 24	8 15 a.m. to 9 42 a.m.	229	203	207	198	...	...	...	...	209
Oct. 2	8 51 a.m. to 10 05 a.m.	...	...	185	196	204	...	...	...	195
Oct. 5	8 57 a.m. to 10 06 a.m.	...	...	182	190	192	...	...	...	188
Oct. 6	8 49 a.m. to 10 00 a.m.	...	...	193	201	206	...	...	...	200
Nov. 21	9 03 a.m. to 9 41 a.m.	...	...	218	207	...	...	...	...	213
1912.										
Jan. 9	8 11 a.m. to 9 24 a.m.	213	209	211	...	...	...	...	...	211
Jan. 10	7 50 a.m. to 8 54 a.m.	214	217	215	...	...	...	...	...	215
Jan. 11	8 38 a.m. to 9 41 a.m.	...	216	192	198	...	...	...	...	202
Jan. 12	8 02 a.m. to 9 01 a.m.	205	207	215	...	...	...	...	...	209
Jan. 13	8 04 a.m. to 9 07 a.m.	198	208	178	...	...	...	...	...	195
Nov. 4	8 25 a.m. to 9 43 a.m.	...	231	223	234	...	...	...	...	229
Nov. 5	8 11 a.m. to 9 11 a.m.	196	198	218	...	...	...	...	...	204
Nov. 6	8 14 a.m. to 9 10 a.m.	190	196	203	...	...	...	...	...	196
Nov. 12	8 21 a.m. to 9 25 a.m.	...	191	178	185	...	...	...	...	185
1913.										
May 14	9 06 a.m. to 11 23 a.m.	...	...	196	197	191	215	210	...	202
1914.										
May 27	8 01 a.m. to 8 38 a.m.	191	179	...	...	...	...	...	...	185
June 2	8 56 a.m. to 9 29 a.m.	...	...	190	179	...	...	...	...	185
June 3	8 53 a.m. to 9 35 a.m.	...	...	189	178	...	...	...	...	184
June 6	9 36 a.m. to 10 08 a.m.	...	...	...	190	177	...	...	...	184
Nov. 5	8 57 a.m. to 9 31 a.m.	...	...	203	203	...	...	...	...	203
Nov. 28	8 53 a.m. to 9 30 a.m.	...	...	211	203	...	...	...	...	207
1915.										
Jan. 20	8 57 a.m. to 10 01 a.m.	...	...	189	195	196	...	...	...	193
Jan. 22	9 50 a.m. to 11 51 a.m.	...	...	...	187	183	187	189	202	190
Feb. 11	9 09 a.m. to 10 29 a.m.	...	...	198	194	192	193	...	...	194
June 1	7 56 a.m. to 8 43 a.m.	183	198	180	...	...	...	...	...	187
June 2	7 49 a.m. to 8 37 a.m.	210	199	196	...	...	...	...	...	202
	Days	10	23	42	36	21	11	10	5	[2]45
	Minimum	183	179	178	178	177	185	189	184	183
	Maximum	229	231	223	234	221	215	210	209	229
	Average	203	201	197	196	195	196	200	197	198
	M. V.	11.3	9.1	9.5	8.0	8.0	7.2	5.3	7.2	7.8

[1]The experimental periods were usually 15 minutes in length and there was but one period in each half hour.
[2]The total number of periods in which the carbon-dioxide was determined in the 45 experiments was 158.

TABLE 38.—*Oxygen consumed at different times of day in respiration experiments; subject, H. L. H., in post-absorptive condition and lying on couch.* (Values per minute.)
Average age, 25 years. Average body-weight (naked), 61.4 kilograms. Height, 172 cm.

Date.	Duration of experiments.	First half hour.[1]	Second half hour.[1]	Third half hour.[1]	Fourth half hour.[1]	Fifth half hour.[1]	Sixth half hour.[1]	Seventh half hour.[1]	Eighth half hour.[1]	Average.
1910.		c.c.	c.c.	c.c.	c.c.	c.c.	c.c.	c.c.	c.c.	c.c.
May 23	8h30m a.m. to 11h05m a.m.	...	234	236	223	...	220	229	...	228
May 28	8 28 a.m. to 11 54 a.m.	...	227	239	231	236	242	253	244	239
June 1	8 35 a.m. to 12 01 p.m.	...	228	246	237	236	233	243	251	239
June 4	8 24 a.m. to 11 07 a.m.	...	226	233	229	236	236	248	...	235
June 9	8 30 a.m. to 11 57 a.m.	...	217	223	206	222	235	210	225	220
June 22	8 41 a.m. to 11 41 a.m.	...	...	225	236	232	237	237	255	237
July 16	8 45 a.m. to 11 19 a.m.	...	241	242	261	256	...	266	...	253
July 25	8 46 a.m. to 11 13 a.m.	...	238	221	236	227	252	243	...	236
1911.										
Mar. 25	8 30 a.m. to 9 40 a.m.	...	242	243	248	...	...	...	...	244
May 17	8 31 a.m. to 9 51 a.m.	...	236	227	234	...	...	...	...	232
May 24	8 40 a.m. to 10 39 a.m.	...	...	...	229	218	225	...	...	224
June 1	8 43 a.m. to 9 38 a.m.	...	...	240	233	...	...	...	...	237
June 7	8 51 a.m. to 9 39 a.m.	...	...	232	231	...	...	...	...	232
July 1	8 58 a.m. to 10 19 a.m.	...	...	224	234	233	...	...	...	230
Sept. 11	8 22 a.m. to 9 36 a.m.	...	246	231	246	...	...	...	...	241
Sept. 20	8 49 a.m. to 10 10 a.m.	...	...	270	263	263	...	...	...	265
Sept. 21	8 48 a.m. to 10 06 a.m.	...	...	282	274	277	...	...	...	278
Sept. 22	8 53 a.m. to 10 06 a.m.	...	...	260	259	265	...	...	...	261
Sept. 23	8 53 a.m. to 10 11 a.m.	...	...	272	259	266	...	...	...	266
Sept. 24	8 15 a.m. to 9 42 a.m.	281	274	270	266	...	...	...	...	273
Oct. 2	8 51 a.m. to 10 05 a.m.	...	...	225	230	241	...	...	...	232
Oct. 4	8 53 a.m. to 10 09 a.m.	...	...	248	249	246	...	...	...	248
Oct. 5	8 57 a.m. to 10 06 a.m.	...	...	237	242	246	...	...	...	242
Oct. 6	8 49 a.m. to 10 00 a.m.	...	...	249	256	257	...	...	...	254
Nov. 21	9 03 a.m. to 9 41 a.m.	...	...	237	243	...	...	...	...	240
1912.										
Jan. 9	8 11 a.m. to 9 24 a.m.	249	254	248	...	...	...	...	...	250
Jan. 10	7 50 a.m. to 8 54 a.m.	245	245	242	...	...	...	...	...	244
Jan. 11	8 38 a.m. to 9 41 a.m.	...	245	229	235	...	...	...	...	236
Jan. 12	8 02 a.m. to 9 01 a.m.	239	232	239	...	...	...	...	...	237
Jan. 13	8 04 a.m. to 9 07 a.m.	239	256	235	...	...	...	...	...	243
Nov. 4	8 25 a.m. to 9 43 a.m.	...	255	244	261	...	...	...	...	253
Nov. 5	8 11 a.m. to 9 11 a.m.	239	237	248	...	...	...	...	...	241
Nov. 6	8 14 a.m. to 9 10 a.m.	242	...	243	...	...	...	...	...	243
Nov. 12	8 21 a.m. to 9 25 a.m.	...	241	241	244	...	...	...	...	242
1913.										
May 14	9 06 a.m. to 11 23 a.m.	...	...	235	231	227	237	242	...	234
1914.										
May 27	8 01 a.m. to 8 38 a.m.	253	237	...	...	...	...	...	...	245
June 2	8 56 a.m. to 9 29 a.m.	...	...	237	224	...	...	...	...	230
June 3	8 53 a.m. to 9 35 a.m.	...	...	221	226	...	...	...	...	224
June 6	9 36 a.m. to 10 08 a.m.	...	...	...	238	230	...	...	...	234
Nov. 5	8 57 a.m. to 9 31 a.m.	...	...	239	237	...	...	...	...	238
Nov. 28	8 53 a.m. to 9 30 a.m.	...	...	237	234	...	...	...	...	236
1915.										
Jan. 20	8 57 a.m. to 10 01 a.m.	...	...	237	235	235	...	...	...	236
Jan. 22	9 50 a.m. to 11 51 a.m.	...	...	...	231	226	226	228	238	230
Feb. 11	9 09 a.m. to 10 29 a.m.	...	...	240	236	242	245	...	...	241
June 1	7 56 a.m. to 8 43 a.m.	223	242	220	...	...	...	...	...	228
June 2	7 49 a.m. to 8 37 a.m.	249	243	244	...	...	...	...	...	245
	Days	10	22	42	37	22	11	10	5	[2]46
	Minimum	223	217	220	206	218	220	210	225	220
	Maximum	281	274	282	274	277	252	266	255	278
	Average	246	241	240	240	242	235	240	243	241
	M. V.	9.7	8.6	9.8	11.2	13.0	6.8	11.1	8.8	9.0

[1]The experimental periods were usually 15 minutes in length and there was but one period in each half hour.
[2]The total number of periods in which the oxygen was determined in the 46 experiments was 159.

Our study of the results of this series has thus far been based solely upon the data obtained regarding the carbon-dioxide production, but a more logical basis of discussion for changes in metabolism is to be found in the values for the oxygen consumption. These are recorded in table 38. Certain data obtained under special abnormal conditions, as an experimentally induced acidosis, are of course excluded, and so far as we are aware the figures given may properly be used for basal values.

The averages at the bottom of the table show that the oxygen consumption per period as the day advanced remained noticeably constant. The highest average (246 c.c.) is that for the first period; the lowest average (235 c.c.) is found for the sixth period. Inasmuch as the average values for the seventh and eighth periods are materially higher than the average found for the sixth period, it is reasonable to consider that the oxygen consumption of H. L. H. shows no general trend toward a decrease in the metabolism, as the measurements continued from 8 a. m. to midday. This conclusion is further justified by the fact that the mean variation from the general average is only 9 c.c. The mean variations for the individual periods, as shown in the last line of the table, agree satisfactorily and give evidence of uniformity in the experimental conditions and accuracy of the experimental work.

The average oxygen consumption of this man over a period of five years, as shown by the general average, is 241 c.c. The averages in the extreme right-hand column indicate that the oxygen consumption, like the carbon-dioxide production, had no general tendency to alter in value as time progressed, with the single exception of a group of five experiments from September 20 to 24, 1911, inclusive. On those days the values approached very closely to an average of 270 c.c. During these five days the subject, although in a post-absorptive condition during the observations, was living on a diet containing a liberal amount of protein and fat but only 125 grams of carbohydrate.[1] This diet was sufficiently low in carbohydrates to alter the metabolism of the subject materially. We do not feel justified, however, in omitting the results from the table.

It may be stated, therefore, that with the subject H. L. H. the average values for both the carbon-dioxide production and oxygen consumption were notably constant, both from period to period and during a period of five years, but that the individual values varied considerably at times.

Experiments with L. E. E.

Another series of experiments was carried out with Mr. L. E. Emmes, who has also long been associated with this laboratory. This series extended from April 26, 1909, to July 29, 1915, inclusive, all but one

[1]Benedict and Higgins, Am. Journ. Physiol., 1912, **30**, p. 217.

of the experiments being made prior to June 6, 1911. Data for 8 half-hour periods, secured approximately between 8 a. m. and 11^h30^m a. m., are available for comparison purposes.

Considering first the table showing the carbon-dioxide production (table 39), it is found that with this subject the average value for the first period is extraordinarily high (224 c.c.), while the subsequent

TABLE 39.—*Carbon dioxide produced at different times of day in respiration experiments; subject L. E. E., in post-absorptive condition and lying on couch.* (Values per minute.)

Average age, 31 years. Average body-weight (naked), 59.8 kilograms. Height, 176 cm.

Date.	Duration of experiments.	First half hour.[1]	Second half hour.[1]	Third half hour.[1]	Fourth half hour.[1]	Fifth half hour.[1]	Sixth half hour.[1]	Seventh half hour.[1]	Eighth half hour.[1]	Average.
1909.		c.c.	c.c.	c.c.	c.c.	c.c.	c.c.	c.c.	c.c.	c.c.
Apr. 26	8^h09^m a.m. to 9^h37^m a.m.	225	200	212	210	...	...	...	...	212
Apr. 28	8 10 a.m. to 9 15 a.m.	222	203	211	...	...	...	...	...	212
Apr. 30	8 03 a.m. to 9 08 a.m.	211	193	203	...	...	...	...	...	202
May 3	8 03 a.m. to 9 15 a.m.	252	217	231	...	...	...	...	...	233
May 7	8 06 a.m. to 9 12 a.m.	246	218	217	...	...	...	...	...	227
May 10	8 32 a.m. to 11 02 a.m.	...	...	196	191	191	204	...	...	196
May 13	8 12 a.m. to 10 47 a.m.	200	207	209	206	209	210	...	...	207
May 20	8 20 a.m. to 10 44 a.m.	234	228	224	216	233	233	...	...	228
May 22	8 40 a.m. to 11 16 a.m.	...	230	221	228	238	249	248	...	236
June 1	8 43 a.m. to 10 56 a.m.	...	215	208	218	204	212	230	...	215
June 9	8 58 a.m. to 11 13 a.m.	...	...	219	201	210	228	219	...	215
June 16	8 29 a.m. to 10 46 a.m.	...	204	198	211	218	217	...	...	210
1910.										
Feb. 4	8 32 a.m. to 11 42 a.m.	...	205	204	203	187	211	201	197	201
Feb. 8	8 38 a.m. to 11 30 a.m.	...	197	195	197	199	187	197	...	195
Mar. 7	8 47 a.m. to 11 52 a.m.	...	...	206	194	199	189	205	190	197
Mar. 19	8 44 a.m. to 11 45 a.m.	...	206	192	199	208	197	209	207	203
Mar. 29	8 29 a.m. to 11 40 a.m.	...	216	178	197	178	195	178	205	192
June 7	8 32 a.m. to 11 45 a.m.	...	199	199	182	...	194	...	198	194
June 11	8 44 a.m. to 11 27 a.m.	...	...	202	195	199	195	208	198	200
July 1	8 47 a.m. to 10 56 a.m.	...	...	193	193	199	196	...	...	195
July 6	8 36 a.m. to 11 10 a.m.	...	202	194	215	194	222	205	...	205
July 14	8 40 a.m. to 11 20 a.m.	...	...	188	191	191	186	191	201	191
Nov. 26	8 25 a.m. to 10 20 a.m.	...	220	220	222	225	...	...	...	222
Nov. 29	9 15 a.m. to 10 59 a.m.	...	...	...	200	207	211	205	...	206
Dec. 3	8 24 a.m. to 9 39 a.m.	...	196	194	201	...	...	...	...	197
Dec. 9	7 59 a.m. to 8 44 a.m.	205	192	...	...	...	...	...	...	199
1911.										
Mar. 23	8 42 a.m. to 9 46 a.m.	...	202	202	209	...	...	...	...	204
May 15	8 44 a.m. to 9 53 a.m.	...	189	189	188	...	...	...	...	189
May 22	8 37 a.m. to 9 44 a.m.	...	184	198	187	...	...	...	...	190
May 29	8 30 a.m. to 10 24 a.m.	...	185	182	178	187	...	...	...	183
June 5	8 48 a.m. to 10 02 a.m.	...	...	187	180	201	...	...	...	189
1915.										
July 29	8 30 a.m. to 12 55 p.m.	...	194	183	...	...	...	...	...	189
	Days	8	24	30	26	20	18	12	7	[2]32
	Minimum	200	184	178	178	178	186	178	190	183
	Maximum	252	230	231	228	238	249	248	207	236
	Average	224	204	202	200	204	208	208	199	204
	M. V.	14.9	9.9	10.8	10.3	11.8	13.9	12.3	4.1	10.8

[1]The experimental periods were usually 15 minutes in length and in most instances there was but one period in the half hour.

[2]The total number of periods in which the carbon-dioxide was determined in the 32 experiments was 148.

values all lie very close to 200 c.c. If we exclude the first period, we find no evidence of change in the value as the day progresses. A closer examination of the figures shows that the high value on the first day is determined, in part at least, by values on May 3 and 7, on which the carbon dioxide excreted was 252 c.c. and 246 c.c., respectively, both values being considerably higher than those found on the subsequent

TABLE 40.—*Oxygen consumed at different times of day in respiration experiments; subject L. E. E., in post-absorptive condition and lying on couch.* (Values per minute.)

Average age, 31 years. Average body-weight (naked), 59.8 kilograms. Height, 176 cm.

Date.	Duration of experiments.	First half hour.[1]	Second half hour.[1]	Third half hour.[1]	Fourth half hour.[1]	Fifth half hour.[1]	Sixth half hour.[1]	Seventh half hour.[1]	Eighth half hour.[1]	Average.
1909.		c.c.	c.c.	c.c.	c.c.	c.c.	c.c.	c.c.	c.c.	c.c.
Apr. 26	8h09m a.m. to 9h37m a.m.	242	243	244	239	...	...	...	...	242
Apr. 28	8 10 a.m. to 9 15 a.m.	236	233	236	...	...	...	...	...	235
Apr. 30	8 03 a.m. to 9 08 a.m.	234	239	248	...	...	...	...	...	240
May 3	8 03 a.m. to 9 15 a.m.	229	236	232	...	...	...	...	...	232
May 7	8 06 a.m. to 9 12 a.m.	243	232	232	...	...	...	...	...	236
May 10	8 32 a.m. to 11 02 a.m.	...	...	242	235	231	243	...	...	238
May 13	8 12 a.m. to 10 47 a.m.	238	246	239	252	235	232	...	...	240
May 20	8 20 a.m. to 10 44 a.m.	241	257	256	249	252	244	...	...	250
May 22	8 40 a.m. to 11 16 a.m.	...	240	252	249	253	263	253	...	252
June 1	8 43 a.m. to 10 56 a.m.	...	268	248	277	252	273	271	...	265
June 9	8 58 a.m. to 11 13 a.m.	...	...	248	247	258	260	274	...	257
June 16	8 29 a.m. to 10 46 a.m.	...	263	280	264	257	264	...	...	266
1910.										
Feb. 4	8 32 a.m. to 11 42 a.m.	...	232	239	248	238	...	259	273	248
Feb. 8	8 38 a.m. to 11 30 a.m.	...	253	235	247	249	247	243	...	246
Mar. 7	8 47 a.m. to 11 52 a.m.	...	...	238	238	245	...	270	...	248
Mar. 19	8 44 a.m. to 11 45 a.m.	...	248	236	244	253	252	236	...	245
Mar. 29	8 29 a.m. to 11 40 a.m.	...	249	235	244	237	238	...	254	243
June 7	8 32 a.m. to 11 45 a.m.	...	244	235	225	...	230	241	249	237
June 11	8 44 a.m. to 11 27 a.m.	...	...	...	234	238	233	241	244	238
July 1	8 47 a.m. to 10 56 a.m.	...	...	248	233	242	240	...	...	241
July 6	8 36 a.m. to 11 10 a.m.	...	232	231	234	237	259	262	...	243
July 14	8 40 a.m. to 11 20 a.m.	...	...	233	231	232	232	235	244	235
Nov. 26	8 25 a.m. to 10 20 a.m.	...	257	248	256	263	...	...	...	256
Nov. 29	9 15 a.m. to 10 59 a.m.	...	...	...	271	261	272	274	...	270
Dec. 3	8 24 a.m. to 9 39 a.m.	...	237	233	237	...	...	...	...	236
Dec. 9	7 59 a.m. to 8 44 a.m.	251	250	...	...	...	...	...	...	251
1911.										
Mar. 23	8 42 a.m. to 9 46 a.m.	...	235	234	240	...	...	...	...	236
May 15	8 44 a.m. to 9 53 a.m.	...	251	241	238	...	...	...	...	243
May 22	8 37 a.m. to 9 44 a.m.	...	254	242	248	...	...	...	...	248
May 29	8 33 a.m. to 10 24 a.m.	...	225	235	243	242	...	...	...	236
June 5	8 48 a.m. to 10 02 a.m.	...	...	237	223	226	...	...	...	229
1915.										
July 29	8 30 a.m. to 12 55 p.m.	...	229	224	...	...	...	...	...	227
	Days	8	24	29	26	20	16	12	5	[2]32
	Minimum	229	225	224	223	226	230	235	244	227
	Maximum	251	268	280	277	263	273	274	273	270
	Average	239	244	241	244	245	249	255	253	244
	M. V.	5.0	9.5	7.5	9.5	9.5	12.6	13.4	8.6	8.1

[1]The experimental periods were usually 15 minutes in length and in most instances there was but on period in the half hour.

[2]The total number of periods in which the oxygen was determined in the 32 experiments was 143.

periods of the same day. The average carbon-dioxide production of this subject over a period of approximately six years was 204 c.c. An examination of the figures in the extreme right-hand column shows a tendency for the carbon-dioxide production to be lower during the last half of the series than during the first half.

When the values for the oxygen consumption given in table 40 are examined, it is seen that the discrepancy in the carbon-dioxide production which was noted for the first period does not appear in the oxygen values. Indeed, there is a possible tendency for the oxygen consumption to increase slightly as the day goes on. The average value for the first half-hour drawn from 8 periods is 239 c.c.; those for the fifth to the eighth periods are all 245 c.c. or over, with the last three perceptibly higher. On the other hand, the average value for the whole series of observations is 244 c.c., which does not indicate a trend toward variation in oxygen consumption as the day progresses. As was the case with H. L. H., variations from period to period on the same day are frequently noted.

The mean variation, like that for the carbon-dioxide production, is small, which is indicative of a satisfactory technique. The values in the extreme right-hand column show that in a period of six years there was no apparent tendency for the oxygen to alter its value to any great extent, but as the last three values are measurably lower than the average, it may be necessary to limit the period of approximately constant metabolism to the time between April 26, 1909, and May 22, 1911, especially as but one value was obtained after June 5, 1911. The data in table 40 give no conclusive evidence, however, that a period of six years is sufficient to alter materially the average metabolism of this subject.

Experiments with J. K. M.

The third subject was a former laboratory assistant, J. K. M. Values for eight periods, *i. e.*, from approximately 8^h30^m a. m. to $12^h 30^m$ p. m., are recorded. The data for the carbon-dioxide production are given in table 41; the general average for the entire series of observations, which is shown in the last line of the table, is 183 c.c. There is no indication of a material change in the metabolism during the forenoon, although wide variations occasionally appear from period to period. The average values for each experiment, which are given in the right-hand column, show that during the period from May 24, 1912, to July 23, 1913, or one year and two months, there was no general tendency for the carbon-dioxide production either to increase or to decrease, as the values for the most part lie quite close to the general average. The chief exceptions are the minimum value of 165 c.c. on June 29, 1912, and the maximum value of 210 c.c. on May 24, 1912. This latter value was obtained on the first day of experimentation, when, owing to the novelty of the situation, the metabolism is usually higher than on subsequent days.

As with the other subjects, the values for the oxygen consumption are more regular than those for the carbon-dioxide production. (See table 42.) The average for the values obtained in each period, as given at the end of the table, show a striking constancy in the metabolism throughout the day, the lowest average being 221 c.c. and the highest 227 c.c. On the other hand, the actual minimum and maximum values obtained in the individual periods show a wide variation. In the

TABLE 41.—*Carbon dioxide produced at different times of day in respiration experiments; subject J. K. M., in post-absorptive condition and lying on couch.* (Values per minute.)

Average age, 23 years. Average body-weight (naked), 60.4 kilograms. Height, 173 cm.

Date.	Duration of experiments.	First half hour.[1]	Second half hour.[1]	Third half hour.[1]	Fourth half hour.[1]	Fifth half hour.[1]	Sixth half hour.[1]	Seventh half hour.[1]	Eighth half hour.[1]	Average.
1912.		c.c.	c.c.	c.c.	c.c.	c.c.	c.c.	c.c.	c.c.	c.c.
May 24	8^h45^m a.m. to 9^h58^m a.m.	...	204	201	224	...	...	...	...	210
May 28	10 00 a.m. to 11 45 a.m.	...	...	...	192	187	202	184	...	191
June 4	8 49 a.m. to 10 30 a.m.	...	193	194	200	192	...	...	...	195
June 11	8 48 a.m. to 11 48 a.m.	...	178	179	...	182	172	194	...	181
June 13	8 39 a.m. to 11 25 a.m.	183	178	177	185	172	185	...	...	180
June 18	8 56 a.m. to 11 41 a.m.	...	177	178	175	173	169	189	...	177
June 20	8 30 a.m. to 11 41 a.m.	175	166	177	186	179	195	181	...	180
June 26	8 51 a.m. to 11 32 a.m.	178	172	165	181	162	174	169	...	172
June 29	8 47 a.m. to 11 21 a.m.	164	163	176	163	152	173	164	...	165
July 1	8 59 a.m. to 11 44 a.m.	...	176	...	175	159	178	169	...	171
July 3	9 02 a.m. to 11 49 a.m.	...	169	167	170	181	196	159	...	174
July 9	9 07 a.m. to 12 01 p.m.	...	181	184	...	174	185	197	...	184
July 12	8 58 a.m. to 11 45 a.m.	...	174	164	176	182	176	179	170	174
July 31	10 42 a.m. to 11 58 a.m.	...	...	...	...	...	177	173	189	180
Sept. 20	8 43 a.m. to 11 29 a.m.	...	175	175	197	198	178	190	...	186
Sept. 21	8 45 a.m. to 11 36 a.m.	177	185	176	174	179	174	184	...	178
Oct. 29	9 30 a.m. to 11 55 a.m.	...	...	198	182	181	194	191	...	189
Oct. 30	8 57 a.m. to 12 15 p.m.	...	185	204	198	172	177	...	183	187
Oct. 31	9 04 a.m. to 12 05 p.m.	...	198	184	176	191	202	201	...	192
Nov. 19	8 55 a.m. to 10 54 a.m.	...	190	202	191	199	186	...	...	194
Nov. 26	9 53 a.m. to 10 49 a.m.	...	...	...	175	178	188	...	...	180
Dec. 3	8 50 a.m. to 11 29 a.m.	...	180	...	186	...	181	...	...	182
Dec. 12	9 35 a.m. to 11 00 a.m.	...	...	181	197	170	188	...	...	184
Dec. 14	10 16 a.m. to 10 57 a.m.	...	...	...	203	176	204	...	...	194
Dec. 15	10 07 a.m. to 10 35 a.m.	...	...	...	182	181	...	...	...	182
1913.										
Jan. 23	8 58 a.m. to 11 52 a.m.	...	188	191	192	175	186	190	...	187
Mar. 14	8 51 a.m. to 11 27 a.m.	...	176	...	182	185	183	179	...	181
Apr. 29	9 38 a.m. to 11 47 a.m.	...	...	180	174	...	171	182	...	177
May 7	9 11 a.m. to 11 34 a.m.	...	180	164	181	173	185	174	...	176
June 5	9 11 a.m. to 12 30 p.m.	...	189	178	171	173	...	...	200	182
July 15	9 07 a.m. to 12 11 p.m.	...	195	178	...	179	...	175	191	184
July 18	9 12 a.m. to 12 58 p.m.	...	...	185	180	172	181	...	178	179
July 23	9 37 a.m. to 12 00 p.m.	...	...	178	...	...	173	194	199	186
	Days	5	23	25	28	28	28	21	7	[2]33
	Minimum	164	163	164	163	152	169	159	170	165
	Maximum	183	204	204	224	199	204	201	200	210
	Average	175	181	181	185	178	183	182	187	183
	M. V.	4.8	8.1	8.7	9.8	7.7	8.0	9.1	8.7	6.3

[1]The experimental periods were usually 15 minutes in length and in all but one instance there was but one period in the half hour.

[2]The total number of periods in which the carbon dioxide was determined in the 33 experiments was 166.

average values for the experimental days a group may be observed from June 20 to July 3, 1912, with an average of 217 c.c., and on June 5 and July 18, 1913, averages of 212 c.c. and 211 c.c. respectively were obtained. Aside from these low values no tendency is shown toward an alteration of the metabolism throughout the period of experimentation and we may fairly state that the average oxygen consumption of this subject as measured during a period of one year and two months is 225 c.c.

TABLE 42.—*Oxygen consumed at different times of day in respiration experiments; subject J. K. M., in post-absorptive condition and lying on couch.* (Values per minute.)

Average age, 23 years. Average body-weight (naked), 60.4 kilograms. Height, 173 cm.

Date.	Duration of experiments.	First half hour.[1]	Second half hour.[1]	Third half hour.[1]	Fourth half hour.[1]	Fifth half hour.[1]	Sixth half hour.[1]	Seventh half hour.[1]	Eighth half hour.[1]	Average.
1912.		c.c.	c.c.	c.c.	c.c.	c.c.	c.c.	c.c.	c.c.	c.c.
May 24	8h45m a.m. to 9h58m a.m.	...	234	237	234	...	...	...	...	235
May 28	10 00 a.m. to 11 45 a.m.	...	...	...	233	212	223	232	...	225
June 4	8 49 a.m. to 10 30 a.m.	...	224	229	221	224	...	...	...	225
June 11	8 48 a.m. to 11 48 a.m.	...	238	230	...	225	227	233	...	231
June 13	8 39 a.m. to 11 25 a.m.	238	224	227	222	217	226	...	...	226
June 18	8 56 a.m. to 11 41 a.m.	...	241	236	233	238	231	247	...	238
June 20	8 30 a.m. to 11 41 a.m.	214	200	213	232	223	225	224	...	219
June 26	8 51 a.m. to 11 32 a.m.	222	215	217	219	216	207	223	...	217
June 29	8 47 a.m. to 11 21 a.m.	224	209	229	208	204	206	220	...	214
July 1	8 59 a.m. to 11 44 a.m.	...	217	...	212	205	211	227	...	214
July 3	9 02 a.m. to 11 49 a.m.	...	215	219	214	223	225	217	...	219
July 9	9 07 a.m. to 12 01 p.m.	...	236	242	227	227	233	235	...	233
July 12	8 58 a.m. to 11 45 a.m.	...	213	219	221	213	214	215	219	216
July 31	10 42 a.m. to 11 58 a.m.	...	...	...	...	...	212	210	221	214
Sept. 20	8 43 a.m. to 11 29 a.m.	...	220	234	242	250	235	233	...	236
Sept. 21	8 45 a.m. to 11 36 a.m.	231	244	233	235	230	233	240	...	235
Oct. 29	9 30 a.m. to 11 55 a.m.	...	...	236	223	227	231	236	...	231
Oct. 30	8 57 a.m. to 12 15 p.m.	...	243	244	...	222	222	...	229	232
Oct. 31	9 04 a.m. to 12 05 p.m.	...	229	215	214	220	221	234	...	222
Nov. 19	8 55 a.m. to 10 54 a.m.	...	245	241	239	223	226	...	...	235
Nov. 26	9 53 a.m. to 10 49 a.m.	...	...	...	220	224	228	...	...	224
Dec. 3	8 50 a.m. to 11 29 a.m.	...	220	...	228	...	219	...	...	222
Dec. 12	9 35 a.m. to 11 00 a.m.	...	...	210	220	216	232	...	...	220
Dec. 14	10 16 a.m. to 10 57 a.m.	...	...	...	246	221	249	...	...	239
Dec. 15	10 07 a.m. to 10 35 a.m.	...	...	...	223	229	...	...	...	226
1913.										
Jan. 23	8 58 a.m. to 11 52 a.m.	...	232	231	227	220	229	239	...	230
Mar. 14	8 51 a.m. to 11 27 a.m.	...	228	...	224	230	233	223	...	228
Apr. 29	9 38 a.m. to 11 47 a.m.	...	...	229	235	...	226	223	...	228
May 7	9 11 a.m. to 11 34 a.m.	...	234	226	225	225	215	222	...	225
June 5	9 11 a.m. to 12 30 p.m.	...	213	206	207	207	...	...	226	212
July 15	9 07 a.m. to 12 11 p.m.	...	238	224	...	217	...	219	220	224
July 18	9 12 a.m. to 12 58 p.m.	...	...	217	216	209	209	...	202	211
July 23	9 37 a.m. to 12 00 m.	...	...	229	...	...	225	225	239	230
	Days	5	23	25	28	28	28	21	7	[2]33
	Minimum	214	200	206	207	204	206	210	202	211
	Maximum	238	245	244	246	250	249	247	239	239
	Average	226	227	227	225	221	224	227	222	225
	M. V.	7.0	10.7	8.2	7.9	7.2	7.5	7.7	7.7	6.5

[1]The experimental periods were usually 15 minutes in length and in all but one instance there was but one period in the half hour.

[2]The total number of periods in whcih the oxygen was determined in the 33 experiments was 166.

EXPERIMENTS WITH OTHER SUBJECTS.

It is impracticable to publish in detail all of the values obtained with the other subjects included in this study, as the mass of data is so extensive. To show the particular point emphasized in this discussion of results, namely, the probable trend of the morning metabolism from 8 a. m. to 1 p. m., an abstract of the results for 29 subjects is presented in tables 43 to 45. These tables show the weight, height, and age of each subject, the limits of the period of time in which the experiments were made, the number of individual periods included in the experi-

TABLE 43.—*Gaseous metabolism at different times of day in respiration experiments; subjects in post-absorptive condition and lying on couch.* (Values per minute.)

Subject, naked weight,[1] height, age.[1]	Time covered by experiments.	Observation.	First half hour.[2]	Second half hour.	Third half hour.	Fourth half hour.	Fifth half hour.	Sixth half hour.	Seventh half hour.	Average of daily averages.
			c.c.	c.c.	c.c.	c.c.	c.c.	c.c.	c. c.	c.c.
DR. M. 75.9 kilos. 175 cm., 29 yr.	29 periods, Apr. 30, 1913, to Dec. 31, 1914.	Avg. CO_2	202	201	204	204	...	...	...	200
		Avg. O_2	256	255	257	263	...	...	...	254
		Days	8	9	8	4	...	...	...	11
W. J. T. 74.6 kilos. 183 cm., 22 yr.	29 periods, Mar. 1, 1913, to May 3, 1913.	Avg. CO_2	215	200	196	198	202	200	...	203
		Days	4	3	5	5	6	3	...	8
		Avg. O_2	255	255	249	251	254	258	...	254
		Days	4	3	5	5	6	4	...	8
J. H. H. 69.3 kilos. 171 cm., 25 yr.	24 periods, Dec. 20, 1912, to Apr. 18, 1913.	Avg. CO_2	198	195	197	190	192	195	195	194
		Avg. O_2	230	231	237	236	234	238	226	233
		Days	3	4	4	3	4	3	2	5
M. J. S. 63.7 kilos. 170 cm., 24 yr.	61 periods, July 19, 1912, to Aug. 6, 1912.	Avg. CO_2	198	195	191	195	192	198	199	195
		Days	5	10	9	12	8	10	5	13
		Avg. O_2	237	233	231	239	234	241	242	235
		Days	4	10	9	12	8	10	5	13
R. G. 62.6 kilos. 173 cm., 23 yr.	27 periods, Dec. 22, 1912, to Feb. 4, 1913.	Avg. CO_2	189	188	197	195	190	187	188	192
		Days	1	5	5	5	3	4	2	6
		Avg. O_2	233	230	231	231	223	223	229	228
		Days	1	5	5	5	3	5	2	6
J. E. F. 60.5 kilos 172 cm., 21 yr.	21 periods, Nov. 22, 1911, to April 6, 1912.	Avg. CO_2	210	207	208	204	204	197	185	206
		Days	4	5	5	2	1	2	2	6
		Avg. O_2	255	236	233	233	223	239	233	237
		Days	4	5	4	2	1	2	2	6
H. B. L. 60.2 kilos. 173 cm., 20 yr.	14 periods, Feb. 20, 1912, to April 5, 1912.	Avg. CO_2	201	192	178	186	191	185	...	187
		Avg. O_2	239	226	216	222	227	225	...	224
		Days	1	3	3	3	2	2	...	3
J. W. P. 56.7 kilos. 172 cm., 30 yr.	18 periods, June 14, 1912, to Oct. 22, 1912	Avg. CO_2	201	202	213	203	197	196	202	201
		Days	3	3	2	2	3	2	2	3
		Avg. O_2	238	235	248	246	245	247	252	243
		Days	3	3	2	2	2	2	2	3
I. A. F. 55.6 kilos. 156 cm., 24 yr.	11 periods, Mar. 26, 1912, to Apr. 4, 1912.	Avg. CO_2	176	186	187	182	185	186	...	184
		Avg. O_2	220	221	221	217	219	224	...	221
		Days	1	2	2	1	2	2	...	2
J. J. G. 50.3 kilos. 164 cm., 21 yr.	29 periods, Mar. 17, 1913, to May 6, 1913.	Avg. CO_2	174	184	174	177	171	165	175	174
		Avg. O_2	194	201	205	210	202	196	206	204
		Days	1	3	7	4	6	3	4	9

[1]Average body-weight and average age for the series of experiments.

[2]The experimental periods were usually 15 minutes in length and in most instances there was but one period in the half hour. The average time of the first period used was at all times approximately between 8 a. m. and 9 a. m.

ments, and the average carbon-dioxide production and oxygen consumption in the successive half hours of the day; also the number of experimental days from which each value is drawn. As in the preceding tables, grand averages are given for each subject for the carbon-dioxide production and oxygen consumption for the total number of experimental days, this being found by averaging the daily averages of each factor for all of the experiments with the individual subjects. The data are arranged according to the weight of the subjects in each group.

As would be expected from the results found in tables 37 to 42, the data indicate that with these subjects, also, there is no noticeable tendency toward an alteration in the basal metabolism as the day progresses, particularly in the values for the oxygen consumption.

TABLE 44.—*Gaseous metabolism at different times of day in respiration experiments; subjects in post-absorptive condition and lying on couch.* (Values per minute.)

Subject, naked weight[1], height, age.[1]	Time covered by experiments.	Observation.	First half hour.[2]	Second half hour.	Third half hour.	Fourth half hour.	Fifth half hour.	Sixth half hour.	Seventh half hour.	Eighth half hour.	Ninth half hour.	Tenth half hour.	Average of daily averages.
			c.c.	c.c.	c.c.	c.c.	c.c.	c.c.	c. c.	c.c.	c.c.	c.c.	c.c.
F. G. B. 83.6 kilos..... 183 cm., 40 yr.	38 periods, Mar. 1, 1909, to Apr. 14, 1915.	Avg. CO_2.	225	216	213	214	225	216	215	213	209	223	214
		Avg. O_2..	261	261	254	255	251	250	249	257	259	274	258
		Days.....	2	6	6	4	1	2	4	4	4	3	10
H. H. A. 62.4 kilos..... 164 cm., 22 yr.	92 periods, Nov. 7, 1911, to Dec. 22, 1912.	Avg. CO_2.	187[3]	181	180	177	178	187	196	190	183	...	180
		Days.....	6	8	16	20	22	8	3	4	2	...	27
		Avg. O_2..	226[3]	214	214	212	213	216	230	223	217	...	214
		Days.....	6	7	15	20	22	8	3	4	2	...	27
S. A. R. 60.8 kilos..... 165 cm., 23 yr.	31 periods, Mar. 30, 1912, to Aug. 14, 1912.	Avg. CO_2.	178	170	172	172	174	166	177	177	191	179	172
		Days.....	1	3	4	5	3	2	4	4	2	3	8
		Avg. O_2..	212	203	200	204	195	200	207	212	210	208	208
		Days.....	1	3	4	5	3	2	5	3	2	3	8
J. B. T. 60.0 kilos..... 171 cm., 20 yr.	70 periods, May 27, 1912, to Jan. 24, 1913.	Avg. CO_2.	188	202	205	210	207	212	210	215	...	...	209
		Days.....	4	10	10	12	10	10	8	3	...	...	12
		Avg. O_2..	246	252	251	249	249	257	249	247	...	...	252
		Days.....	4	10	9	12	10	11	7	3	...	...	12
W. F. B. 59.9 kilos..... 168 cm., 32 yr.	30 periods, Mar. 10, 1913, to July 22, 1913.	Avg. CO_2.	184	207	200	197	195	197	190	181	...	...	198
		Avg. O_2..	219	235	231	229	227	220	244	241	...	...	230
		Days.....	1	4	6	4	6	5	2	2	...	...	7
D. J. M. 58.0 kilos..... 175 cm., 20 yr.	31 periods, Mar. 21, 1910, to May 20, 1910.	Avg. CO_2.	211	190	183	184	190	187	194	185	214	...	188
		Days.....	1	5	5	5	2	4	3	4	2	...	5
		Avg. O_2..	239	233	231	224	232	234	236	232	240	...	232
		Days.....	1	5	5	4	2	5	3	4	2	...	5
A. G. E. 57.0 kilos..... 169 cm., 25 yr.	63 periods, Mar. 24, 1910, to Mar. 28, 1911.	Avg. CO_2.	200	197	195	200	191	195	190	194	...	...	194
		Avg. O_2..	221	217	221	217	215	212	219	220	...	...	217
		Days.....	7	10	10	10	10	8	6	2	...	...	13
P. F. J. 57.0 kilos..... 167 cm., 20 yr.	93 periods, Feb. 5, 1912, to Nov. 14, 1912.	Avg. CO_2.	196	196	191	191	190	184	187	189	191	193	192
		Days.....	1	15	13	15	10	10	9	8	3	3	18
		Avg. O_2..	234	230	232	230	227	226	234	243	247	249	233
		Days.....	1	15	13	15	10	10	10	8	3	3	18

[1]Average body-weight and average age for the series of experiments.

[2]The experimental periods were usually 15 minutes in length and in most instances there was but one period in the half hour. The average time of the first period used was at all times approximately between 8 a. m. and 9 a. m., except as otherwise noted.

[3]The average time of beginning the first period with this subject was 6^h30^m a. m.

An examination of the detailed tables from which this abstract is made shows even more strikingly than with the subjects trained in the use of the apparatus, as were H. L. H., L. E. E., and J. K. M., that there were considerable variations in the individual values. While most of the material from which this abstract is drawn was more fragmentary than that given for the three subjects in detail, there is no evidence of a tendency for the metabolism to change in either direction during the period of experimentation.

CONCLUSIONS REGARDING SHORT-PERIOD EXPERIMENTS.

The results just discussed were obtained with men in good health, from 17 to 40 years of age. Unfortunately the observations of the metabolism of individuals over 30 years of age are not so extended as they should be; we are thus unable to state definitely that the lowering of the metabolism noted in practically all instances with people of advanced years had not already begun with the subjects about 40 years of age, but our evidence thus far obtained does not lead us to infer this.

In any attempt to draw general conclusions from these short-period experiments we should depend more especially upon the values found for the oxygen consumption, as, being uninfluenced by the previous diet, they give a clearer picture of the actual metabolism. A general review of the results in tables 37 to 42 and of the results from which the average values in tables 43 to 45 are drawn shows that with all of the subjects the individual values fluctuated considerably at times, but that the average values from period to period indicate no general change one way or the other. The average values for the experiments during a period of several months or years show a general constancy in the metabolism, there being but few average values which vary widely from the general average for the whole period. This is emphasized by the fact that the general mean variations for the various subjects were not large. The general constancy in the metabolism during the different hours of the day and during different months and years thus seems to be fairly well established by these data, at least for individuals between 17 and 40 years of age.

The variations in the individual values make clear the fact that single determinations should not be relied upon and that in order to obtain a value for the basal metabolism it is necessary to secure two or three well-agreeing periods for averaging. Inasmuch as the average values from period to period did not tend to change in any one direction, they were evidently free from diurnal influence; this factor may therefore be eliminated in considering the results of comparison experiments in which the metabolism during fast is first determined and subsequently the metabolism after food. This leads us, therefore, to the general conclusion that the determination of basal values immediately prior to the ingestion of food is the most logical and satisfactory method for studying the small changes in the metabolism frequently noted after the ingestion of food.

TABLE 45.—*Gaseous metabolism at different times of day in respiration experiments;*

Subject, naked weight,[1] height, age.[1]	Time covered by experiments.	Observation.	First half hour.[2]	Second half hour.	Third half hour.	Fourth half hour.	Fifth half hour.	Sixth half hour.	Seventh half hour.	Eighth half hour.
			c.c.	*c.c.*	*c.c.*	*c.c.*	*c.c.*	*c.c.*	*c.c.*	*c.c.*
H. R. R. 69.5 kilos, 185 cm., 19 yr.	11 periods, Apr. 22, 1915, to April 23, 1915.	Avg. CO_2.	216	208	211	...	...	...	...	...
		Avg. O_2..	278	272	270	...	...	...	...	...
		Days.....	2	2	2	...	...	...	...	...
A. J. O. 69.3 kilos, 180 cm., 30 yr.	100 periods, Nov. 4, 1914, to Feb. 8, 1915.	Avg. CO_2.	216	214	208	207	206	202	208	200
		Avg. O_2..	252	250	247	247	254	247	259	241
		Days.....	6	22	20	13	4	3	2	1
K. H. A. 66.4 kilos, 182 cm., 26 yr.	139 periods, July 27, 1911, to June 26, 1912.	Avg. CO_2.	203[3]	189	185	197	192	194	194	193
		Days.....	1	1	3	12	23	19	18	12
		Avg. O_2..	252[3]	228	241	241	242	238	236	238
		Days.....	1	1	2	12	23	18	18	12
J. R. 66.0 kilos, 182 cm., 27 yr.	54 periods, Feb. 25, 1909, to June 2, 1909.	Avg. CO_2.	231[3]	211	213	202	199	200	204	200
		Days.....	1	1	4	7	10	7	6	6
		Avg. O_2..	252[3]	244	237	242	244	246	244	245
		Days.....	1	1	4	8	9	7	6	6
J. J. C. 65.0 kilos, 175 cm., 26 yr.	258 periods, Feb. 26, 1909, to Apr. 25, 1911.	Avg. CO_2.	194	193	191	193	189	188	189	191
		Days.....	2	12	37	38	42	29	26	24
		Avg. O_2..	241	229	231	230	229	225	227	229
		Days.....	2	11	35	38	40	28	24	23
H. W. F. 58.0 kilos, 174 cm., 25 yr.	41 periods, Jan. 27, 1915, to July 30, 1915.	Avg. CO_2.	178	162	164	172	...	...	...	...
		Avg. O_2..	224	205	210	223	...	...	...	...
		Days.....	3	5	2	1	...	...	...	...
H. F. T. 57.8 kilos, 179 cm., 32 yr.	272 periods, June 8, 1911, to Jan. 30, 1912.	Avg. CO_2.	168[4]	158	158	173	168	172	171	167
		Days.....	6	9	10	11	19	28	20	27
		Avg. O_2..	200[4]	191	192	195	198	193	194	194
		Days.....	6	7	9	11	20	27	20	26
V. G. 54.7 kilos, 162 cm., 17 yr.	63 periods, Nov. 4, 1910, to Mar. 11, 1911.	Avg. CO_2.	201	194	190	197	198	219	204	190
		Days.....	6	11	11	9	4	1	5	1
		Avg. O_2..	240	229	228	229	236	233	231	230
		Days.....	6	11	11	9	4	1	5	1
T. H. H. 54.5 kilos, 171 cm., 29 yr.	44 periods, Feb. 17, 1915, to Mar. 31, 1915.	Avg. CO_2.	176	179	182	175	167	...	...	...
		Avg. O_2..	205	205	207	199	199	...	...	...
		Days.....	3	10	10	4	1	...	...	...
W. K. 49.7 kilos, 162 cm., 29 yr.	39 periods, Feb. 20, 1915, to July 16, 1915.	Avg. CO_2.	167	169	164	163	...	...	...	...
		Avg. O_2..	196	200	194	201	...	...	...	...
		Days.....	3	6	5	1	...	...	...	...
T. M. C. 48.5 kilos, 165 cm., 32 yr.	100 periods, Mar. 23, 1909, to May 27, 1914.	Avg. CO_2.	168	157	154	152	152	153	155	156
		Days.....	4	10	13	17	15	14	11	9
		Avg. O_2..	183	188	184	183	180	183	187	188
		Days.....	4	9	14	14	14	14	10	9

[1]Average body-weight and average age for the series of experiments.

[2]The experimental periods were usually 15 minutes in length and in most instances there was but one period in the half hour. The average time of the first period used was at all times approximately between 8 a. m. and 9 a. m., except as otherwise noted.

[3]The average time of the first period with this subject was 7 a. m.

[4]The average time of the first period with this subject was 6^h30^m a. m.

subjects in post-absorptive condition and lying on couch. (Values per minute.)

Ninth half hour.	Tenth half hour.	Eleventh half hour.	Twelfth half hour.	Thirteenth half hour.	Fourteenth half hour.	Fifteenth half hour.	Sixteenth half hour.	Seventeenth half hour.	Eighteenth half hour.	Nineteenth half hour.	Twentieth half hour.	Twenty-first half hour.	Average of daily averages.	Subject, naked, weight,[1] height, age.[1]
c.c.	c.c.	c.c.	c.c.	c.c.	c.c.	c.c.	c.c.	c.c.	c.c.	c.c.	c.c.	c.c.	c.c.	
218	219	209	....	....	....	....	....	....	....	....	....	....	213	H. R. R.
289	292	285	....	....	....	....	....	....	....	....	....	....	280	69.5 kilos, 185 cm., 19 yr.
1	2	2	....	....	....	....	....	....	....	....	....	....	2	
199	205	212	203	205	....	....	....	....	....	....	....	....	210	A. J. O.
247	251	252	247	254	....	....	....	....	....	....	....	....	249	69.3 kilos, 180 cm., 30 yr.
1	2	3	4	4	....	....	....	....	....	....	....	....	24	
198	190	194	194	194	190	201	....	....	....	....	....	....	194	K. H. A.
11	13	10	4	4	2	2	....	....	....	....	....	....	28	66.4 kilos, 182 cm., 26 yr.
237	232	236	235	242	236	240	....	....	....	....	....	....	239	
11	13	10	4	4	2	2	....	....	....	....	....	....	28	
207	199	188	....	....	....	....	....	....	....	....	....	....	202	J. R.
6	3	2	....	....	....	....	....	....	....	....	....	....	12	66.0 kilos, 182 cm., 27 yr.
245	253	240	....	....	....	....	....	....	....	....	....	....	243	
6	3	2	....	....	....	....	....	....	....	....	....	....	12	
191	189	188	193	196	208	206	204	191	....	....	....	....	191	J. J. C.
16	8	3	3	2	1	2	4	3	....	....	....	....	52	65.0 kilos, 175 cm., 26 yr.
234	234	237	242	229	243	233	240	240	....	....	....	....	230	
15	7	3	2	2	1	2	4	3	....	....	....	....	52	
168	172	185	180	176	171	....	....	....	....	....	....	....	172	H. W. F.
206	211	231	224	217	213	....	....	....	....	....	....	....	214	58.0 kilos, 174 cm., 25 yr.
2	2	1	3	4	4	....	....	....	....	....	....	....	9	
161	165	156	163	153	159	157	159	149	155	156	158	167	165	H. F. T.
16	20	15	16	11	9	10	10	3	4	3	3	3	44	57.8 kilos, 179 cm., 32 yr.
189	194	185	187	179	186	185	190	181	190	189	189	188	192	
16	19	15	16	11	9	10	10	3	4	3	3	3	44	
198	196	195	191	199	....	....	....	....	....	....	....	....	195	V. G.
3	4	2	3	3	....	....	....	....	....	....	....	....	14	54.7 kilos, 162 cm., 17 yr.
231	240	230	233	233	....	....	....	....	....	....	....	....	231	
3	3	1	3	3	....	....	....	....	....	....	....	....	14	
...	...	188	185	183	186	....	....	....	....	....	....	....	180	T. H. H.
...	...	226	220	217	206	....	....	....	....	....	....	....	207	54.5 kilos, 171 cm., 29 yr.
...	...	2	5	4	2	....	....	....	....	....	....	....	12	
151	159	166	169	178	170	175	165	....	....	....	....	....	168	W. K.
166	192	199	205	217	190	202	197	....	....	....	....	....	200	49.7 kilos, 162 cm., 29 yr.
1	3	5	3	1	1	2	2	....	....	....	....	....	8	
161	165	162	....	....	....	....	....	....	....	....	....	....	154	T. M. C.
3	2	2	....	....	....	....	....	....	....	....	....	....	18	48.5 kilos, 165 cm., 32 yr.
196	188	190	....	....	....	....	....	....	....	....	....	....	184	
4	2	2	....	....	....	....	....	....	....	....	....	....	18	

USE OF AVERAGE BASAL VALUES FOR COMPARISON.

A considerable amount of experimental evidence has accumulated regarding the relationship of the average basal values of different individuals.[1] The comparison of the results obtained with different subjects has been much discussed, together with the varying effects upon them of the factors influencing the basal metabolism, such variations depending upon the different conditions of nutriment and environment. Here, however, we are particularly interested only in those factors which influence the basal metabolism of a single individual. The question arises: To what extent is it possible to determine the basal metabolism of a subject and assume that this value is constant and may be logically used as a general base-line for food experiments subsequently carried out?

When several basal experiments have been made with a subject, and a number of closely agreeing results have been obtained for that particular day, many investigators use this average basal value for comparison with results obtained on subsequent days without further comment. The short-period method admits of the duplication of experimental periods for comparison in securing an average basal value, but it is by no means certain that the general use of such a value is the wisest or the most satisfactory procedure.

It is obvious that the metabolism will be somewhat affected by a material alteration in the body-weight, such as may take place in the course of a year or, with a growing individual, in a very much shorter space of time. A base-line determined under materially different weight conditions may not therefore be used for general comparison.

Furthermore, seasonal variations may be possible. For example, we may ask whether a base-line determined in the winter may be logically used for comparison in the summer. One of the most striking illustrations of seasonal variation was given in some observations made at the Massachusetts General Hospital upon Palmer.[2] With essentially the same body-weight, the subject showed in summer a total heat production of 1,797 calories, 19.2 calories per kilogram of body-weight, and 707 calories per square meter of body-surface; in winter he had a total heat production of 2,004 calories, 21.4 calories per kilogram of body-weight, and 789 calories per square meter of body-surface.

The question of possible seasonal variation has also been considered in connection with the results of our short-period experiments. To this end the values obtained for the consumption of oxygen per minute in the individual months have been averaged in table 46 for each subject who was studied during a period of at least $7\frac{1}{2}$ months. The longest period of time during which experiments were made was that for

[1]Benedict, Emmes, Roth, and Smith, Journ. Biol. Chem., 1914, **18**, p. 139; Benedict, *ibid.*, 1915, **20**, p. 263.

[2]Palmer, Means, and Gamble, Journ. Biol. Chem., 1914, **19**, pp. 242 and 243.

L. E. E. of 6¼ years. With none of the subjects were values obtained for every month in the year. The primary object in giving these average values is to note if there is a tendency for the metabolism to be distinctly higher at one season than another.

TABLE 46.—*Average oxygen consumption in different months of the year in respiration experiments without food.*[1] (Values per minute.)

Month.	H. H. A.	K. H. A.	F. G. B.	J. J. C.	T. M. C.	A. G. E.	L. E. E.	H. L. H.	P. F. J.	Dr. M.	J. K. M.	M. A. M.	H. F. T.	J. B. T.
	c.c.	c.c.	c.c.	c.c.	c.c.	c.c.	c.c.	c.c.	c.c.	c.c.	c.c.	c.c.	c.c.	c.c.
Jan..	218	...	259	235	...	...	...	239	...	...	230	244	195	252
Feb..	217	230	...	231	188	...	247	241	244	...	...	239	...	...
Mar.	220	249	266	235	188	218	243	244	240	...	228	251	...	...
Apr..	...	...	268	229	...	215	239	...	251	290	228	238	...	...
May.	...	232	243	218	183	215	242	234	232	252	228	...	...	249
June.	...	237	253	223	181	217	249	233	226	232	223	...	205	250
July.	...	238	...	...	176	220	237	240	219	...	220	...	189	...
Aug..	...	238	...	...	...	...	...	...	...	...	...	...	184	...
Sept.	...	241	...	...	...	...	...	[2]264	...	...	236	...	191	253
Oct..	...	...	...	...	...	...	...	244	...	...	228	...	...	244
Nov.	200	...	250	229	191	...	263	242	237	250	230	...	...	245
Dec..	212	240	...	230	...	...	244	...	...	259	227	237	...	281

[1]This table includes all subjects on whom experiments were made during a period of at least 7½ months, the longest period being 6¼ years with subject L. E. E.

[2]See explanation of this high value on page 103.

Examining the data for differences from month to month, we find that with H. H. A. the minimum of 200 c.c. occurs in November and that the maximum of 220 c.c. is found in March, with a difference of 10 per cent. In this particular case, therefore, the basal value determined in November can not properly be used for studying small increments measured in March. It does not follow, however, that we should invariably expect with H. H. A. a low metabolism in November with a higher metabolism in March.

With the subject K. H. A. the variations are extremely small; the minimum value (230 c.c.) was found in February and the maximum (249 c.c.) in March. With F. G. B. a minimum of 243 c.c. was found in May and a maximum of 268 c.c. in April; with J. J. C. a minimum of 218 c.c. in May and a maximum of 235 c.c. in January and March; with T. M. C. a minimum of 176 c.c. in July and a maximum of 191 c.c. in November. The values for A. G. E. are practically constant for the 5 months during which he was measured. With L. E. E. a minimum of 237 c.c. was obtained in July and a maximum of 263 c.c. in November; with H. L. H. a minimum of 233 c.c. in June and a maximum of 264 c.c. in September; with P. F. J. a minimum of 219 c.c. in July and a maximum of 251 c.c. in April; with Dr. M. a minimum of 232 c.c. in June and a maximum of 290 c.c. in April; with J. K. M.

a minimum of 220 c.c. in July and a maximum of 236 c.c. in September; with M. A. M. a minimum of 237 c.c. in December and a maximum of 251 c.c. in March; with H. F. T. a minimum of 184 c.c. in August and a maximum of 205 c.c. in June; while with J. B. T. a minimum was found of 244 c.c. in October and a maximum of 281 c.c. in December. It is thus clear that the metabolism of these subjects, as indicated by oxygen measurements alone, does not show regular seasonal variations, but only noticeable differences in averages from month to month.

Although in table 46 we have recorded only the oxygen measurements, yet it is evident that with these normal individuals the respiratory quotient in the post-absorptive condition remains reasonably uniform at 0.85, so that for purposes of comparison we may assume that the oxygen consumption corresponds to the heat production. While, therefore, the data show somewhat large differences in the metabolism for the different months with different individuals, there is no uniformity other than the possible tendency for the high values to fall in the month of March, this occurring with four subjects, and for the minimum metabolism to fall in July, as also found with four subjects; but the results are not sufficiently uniform to draw definite conclusions as to the maximum and minimum metabolism occurring in these two months.

The possible fluctuations in the metabolism have likewise been shown for 35 subjects[1] who were studied for periods of time varying from 5 days to 4 years and 5 months. In all cases the subjects were in the post-absorptive condition and with complete muscular repose. The increase in the oxygen consumption is used as an index of the fluctuations of the metabolism, with the value for the minimum daily average as a basis. The figures indicate that the oxygen consumption varied above the minimum from 3.5 per cent to 31.3 per cent, with an average variation of 13.9 per cent. The greatest variations were found as a rule with those subjects studied for the longer periods.

The results obtained with many of these subjects were considered in more detail in the preceding section. By reference to tables 37 to 45 it will be seen that while the average values showed usually no tendency to change materially during the months or years the subjects were studied, yet the values for the individual periods often fluctuated widely. With such fluctuations it would not be logical to use a basal metabolism determined on one day for comparison with the metabolism determined on another day, except possibly when the superimposed factor to be measured is of considerable size, as in severe muscular work.

With well-trained subjects of long experience, an average basal value may be considered as more reliable than those obtained with untrained subjects. Perhaps one of the best illustrations of the constancy of metabolism with a thoroughly well trained subject is that of the professional bicycle rider, M. A. M., studied by Benedict and Cathcart,[2]

[1]Benedict, Journ. Biol. Chem., 1915, **20,** p. 263, table 4.
[2]Benedict and Cathcart, Carnegie Inst. Wash. Pub. No. 187, 1913.

whose metabolism was determined practically every morning for several months. (See tables 47 and 48.) The uniformity of the average metabolism for the day throughout this extended period is striking, to say the least, the variations in the metabolism being small. In fact, these particular experiments have been cited as conclusive evidence that when the base-line has once been fairly established it may, with propriety, suffice as a common base-line for subsequent use. But in physiological experimenting of this kind a subject is rarely so completely under control that he can be used daily for several weeks and even months in experiments with a respiration apparatus. Such conditions have never, we believe, been duplicated in experiments in which the influence of the ingestion of food had been primarily considered.

In studying a superimposed factor with a great increase in metabolism, such as that commonly occurring in severe muscular work experiments, the use of a common base-line is open to the least objection, but most factors have a less pronounced effect upon the metabolism than severe muscular work. Even with so constant a metabolism as that of M. A. M., it would be impossible to use an average basal value in many experiments with him on the influence of the ingestion of food, for the variations in the metabolism in the supposedly satisfactory collection of basal values were at times plus or minus 5 or 10 per cent, and the total effect of many processes of digestion fall well within this limit.

The constancy in the average metabolism shown in tables 37 to 45 confirm in practically every detail the general conclusions drawn by Gigon[2] from the basal data obtained by him with the Sondén-Tigerstedt

TABLE 47.—*Carbon dioxide produced at different times of day in respiration experiments; subject M. A. M., in post-absorptive condition and lying on couch.* (Values per minute.)

Average age, 29 years. Average body-weight (naked), 66.0 kilograms. Height, 177 cm.

Date.	Duration of experiments.	First half hour.[1]	Second half hour.[1]	Third half hour.[1]	Fourth half hour.[1]	Fifth half hour.[1]	Sixth half hour.[1]	Average.
1911.		*c.c.*	*c.c.*	*c.c.*	*c.c.*	*c.c.*	*c.c.*	*c.c.*
Dec. 7	9^h04^m a.m. to 10^h41^m a.m.	...	229	227	219	226	...	225
8	8 37 a.m. to 10 04 a.m.	203	203	202	211	...	...	205
11	10 11 a.m. to 11 16 a.m.	...	...	...	194	190	200	195
12	8 57 a.m. to 10 02 a.m.	...	202	197	195	...	...	198
13	8 33 a.m. to 9 37 a.m.	200	196	203	...	...	...	200
14	8 50 a.m. to 9 52 a.m.	...	217	214	216	...	...	216
15	8 29 a.m. to 9 31 a.m.	202	205	194	...	...	...	200
19	8 32 a.m. to 9 34 a.m.	204	200	196	...	...	...	200
20	8 25 a.m. to 9 19 a.m.	203	194	186	...	...	...	194
21	8 22 a.m. to 9 15 a.m.	202	199	196	...	...	...	199
22	8 27 a.m. to 9 22 a.m.	199	195	188	...	...	...	194

[1]The experimental periods were usually 15 minutes in length and there was but one period in each half hour.

[2]Gigon, Münch. med. Wochenschr., 1911, **58**, p. 1343.

TABLE 47 (continued).—*Carbon dioxide produced at different times of day in respiration experiments; subject M. A. M., in post-absorptive condition and lying on couch.*—(Values per minute.)

Date.	Duration of experiments.	First half hour.[1]	Second half hour.[1]	Third half hour.[1]	Fourth half hour.[1]	Fifth half hour.[1]	Sixth half hour.[1]	Average.
1912.		c.c.	c.c.	c.c.	c.c.	c.c.	c.c.	c.c.
Jan. 1	9 33 a.m. to 8 35 a.m...	206	208	209	...	...	...	208
2	8 49 a.m. to 9 26 a.m...	...	198	200	...	...	...	199
3	8 26 a.m. to 9 24 a.m...	201	199	201	...	...	...	200
4	8 26 a.m. to 8 41 a.m...	214	...	...	...	...	...	214
5	8 29 a.m. to 8 44 a.m...	213	...	...	...	...	...	213
8	8 34 a.m. to 9 10 a.m...	205	204	...	...	...	...	205
9	8 30 a.m. to 9 10 a.m...	215	207	...	...	...	...	211
10	8 29 a.m. to 9 07 a.m...	206	211	...	...	...	...	209
12	8 34 a.m. to 9 10 a.m...	228	217	...	...	...	...	223
15	8 33 a.m. to 9 11 a.m...	235	229	...	...	...	...	232
16	8 36 a.m. to 9 14 a.m...	212	210	...	...	...	...	211
17	8 30 a.m. to 9 10 a.m...	196	187	...	...	...	...	192
18	8 30 a.m. to 9 09 a.m...	197	205	...	...	...	...	201
19	8 29 a.m. to 9 43 a.m...	196	200	201	...	...	...	199
23	8 42 a.m. to 9 47 a.m...	211	211	209	...	...	...	210
24	8 34 a.m. to 9 13 a.m...	210	192	...	...	...	...	201
25	8 36 a.m. to 9 40 a.m...	202	201	195	...	...	...	199
26	8 32 a.m. to 9 11 a.m...	204	200	...	...	...	...	202
31	8 35 a.m. to 9 44 a.m...	227	221	218	...	...	...	222
Feb. 1	8 46 a.m. to 9 26 a.m...	...	212	216	...	...	...	214
2	8 40 a.m. to 9 43 a.m...	214	202	195	...	...	...	204
6	8 47 a.m. to 11 50 a.m...	...	208	211	221	213	[2]208	[2]210
7	8 35 a.m. to 9 36 a.m...	206	190	189	...	...	...	195
8	8 36 a.m. to 9 31 a.m...	208	206	208	...	...	...	207
9	8 38 a.m. to 9 39 a.m...	196	191	183	...	...	...	190
13	8 38 a.m. to 9 43 a.m...	204	192	193	...	...	...	196
14	8 36 a.m. to 9 39 a.m...	206	194	207	...	...	...	202
15	8 38 a.m. to 9 36 a.m...	191	187	187	...	...	...	188
16	8 40 a.m. to 9 40 a.m...	199	191	188	...	...	...	193
20	8 46 a.m. to 9 49 a.m...	189	209	203	...	...	...	200
21	8 39 a.m. to 9 44 a.m...	195	188	191	...	...	...	191
23	9 05 a.m. to 9 43 a.m...	...	209	200	...	...	...	205
26	8 41 a.m. to 9 45 a.m...	203	195	200	...	...	...	199
27	8 40 a.m. to 9 42 a.m...	218	202	208	...	...	...	209
29	8 41 a.m. to 9 41 a.m...	202	229	217	...	...	...	216
Mar. 6	8 47 a.m. to 10 01 a.m...	...	235	229	225	...	...	230
11	8 44 a.m. to 9 22 a.m...	...	218	212	...	...	...	215
20	12 45 p.m. to 2 02 p.m...	...	...	...	...	...	...	[3]200
22	8 22 a.m. to 10 35 a.m...	210	216	212	219	211	...	214
26	8 43 a.m. to 9 20 a.m...	210	202	...	...	...	...	206
29	8 43 a.m. to 9 50 a.m...	214	236	206	212	...	...	217
Apr. 16	8 38 a.m. to 9 34 a.m...	234	207	212	...	...	...	218
1914.								
Apr. 18	8 24 a.m. to 10 03 a.m...	198	186	196	193	...	...	193
	Days.....	43	50	39	10	4	2	[4]54
	Minimum.....	189	186	183	193	190	200	188
	Maximum.....	235	236	229	225	226	208	232
	Average.....	207	205	203	211	210	204	205
	M. V.....	7.8	9.7	9.0	9.7	10.0	4.0	8.4

[1]The experimental periods were usually 15 minutes in length and there was but one period in each half hour.

[2]Two other results (seventh period, 207 c.c., and eighth period, 202 c.c.) were obtained and included in the average for the day.

[3]Average of results obtained in ninth to twelfth periods, 208, 190, 201, and 202 c.c., respectively.

[4]The total number of periods in which the carbon dioxide was determined in the 54 experiments was 154.

apparatus in Stockholm and the Jaquet apparatus in Basel, and subsequently by means of another apparatus employing a spirometer, Müller valves, and mouthpiece, in the Poliklinik in Basel. Since the data obtained with the Stockholm apparatus were exclusively confined to carbon-dioxide production, they can not be taken as comparable values for indicating constancy in the total heat production. Nevertheless it is important to note that, even on the basis of the figures presented by Gigon, variations of nearly 10 per cent are found, which far exceed in many instances the variations found in observations following the ingestion of the several foodstuffs.

Accordingly, in the final selection of a determined basal value, it is of fundamental importance that we should bear in mind the fact that in averaging a large number of experiments the tendency is for all of the irregularities to be eliminated. For a comparison with an average value obtained from a large number of food experiments it may be justifiable to use a basal value of this kind, but in a comparison with the results of only one or two food experiments the variations in the single periods must be taken into consideration.

While in this research our experience in securing a general basal value for use is by no means satisfactory, it has occasionally been necessary to use an average base-line. Inasmuch as a large number of values were secured, it is probable that any variations in the individual values will be more or less eliminated in the grand average. Nevertheless it is quite clear that a general base-line, even for a well-trained subject who is experimented upon each day, can not properly be used for studying the minor factors influencing basal metabolism, such as may be found in connection with the ingestion of certain of the food materials studied.

TABLE 48.—*Oxygen consumed at different times of day in respiration experiments; subject M. A. M., in post-absorptive condition and lying on couch.* (Values per minute.)

Average age, 29 years. Average body-weight (naked), 66.0 kilograms. Height, 177 cm.

Date.	Duration of experiments.	First half hour.[1]	Second half hour.[1]	Third half hour.[1]	Fourth half hour.[1]	Fifth half hour.[1]	Sixth half hour.[1]	Average.
1911.		c.c.	c.c.	c.c.	c.c.	c.c.	c.c.	c.c.
Dec. 7	9^h04^m a.m. to 10^h41^m a.m.	...	251	262	277	257	...	262
8	9 21 a.m. to 10 04 a.m.	...	...	246	247	...	...	247
11	10 11 a.m. to 11 16 a.m.	...	...	...	232	243	238	238
12	9 22 a.m. to 10 02 a.m.	...	...	233	226	...	...	230
13	8 33 a.m. to 9 37 a.m.	226	222	231	...	...	...	226
14	8 50 a.m. to 9 52 a.m.	...	241	237	235	...	...	238
15	8 29 a.m. to 9 31 a.m.	254	252	245	...	...	...	250
19	8 32 a.m. to 9 34 a.m.	235	250	229	...	...	...	238
20	8 25 a.m. to 9 19 a.m.	226	227	225	...	...	...	226
21	8 22 a.m. to 9 15 a.m.	230	231	231	...	...	...	231
22	8 27 a.m. to 9 22 a.m.	229	217	229	...	...	...	225

[1]The experimental periods were usually 15 minutes in length and there was but one period in each half hour.

TABLE 48 (continued).—*Oxygen consumed at different times of day in respiration experiments; subject M. A. M., in post-absorptive condition and lying on couch.* (Values per minute.)

Date.	Duration of experiments.	First half hour.[1]	Second half hour.[1]	Third half hour.[1]	Fourth half hour.[1]	Fifth half hour.[1]	Sixth half hour.[1]	Average.
1912.		c.c.	c.c.	c.c.	c.c.	c.c.	c.c.	c.c.
Jan. 1	8 33 a.m. to 9 35 a.m...	232	233	233	...	...	...	233
2	8 49 a.m. to 9 26 a.m...	...	231	232	...	...	...	232
3	8 26 a.m. to 9 24 a.m...	233	237	229	...	...	...	233
4	8 26 a.m. to 8 41 a.m...	235	...	...	...	...	...	235
5	8 29 a.m. to 8 44 a.m...	233	...	...	...	...	...	233
8	8 34 a.m. to 9 10 a.m...	228	234	...	...	...	...	231
9	8 30 a.m. to 9 10 a.m...	237	246	...	...	...	...	242
10	8 29 a.m. to 9 07 a.m...	258	259	...	...	...	...	259
12	8 34 a.m. to 9 10 a.m...	266	259	...	...	...	...	263
15	8 33 a.m. to 9 11 a.m...	266	249	...	...	...	...	258
16	8 36 a.m. to 9 14 a.m...	250	245	...	...	...	...	248
17	8 30 a.m. to 9 10 a.m...	253	249	...	...	...	...	251
18	8 30 a.m. to 9 09 a.m...	255	267	...	...	...	...	261
19	8 29 a.m. to 9 43 a.m...	252	269	259	...	...	...	260
23	8 42 a.m. to 9 47 a.m...	252	240	247	...	...	...	246
24	8 34 a.m. to 9 13 a.m...	230	234	...	...	...	...	232
25	8 36 a.m. to 9 40 a.m...	260	236	251	...	...	...	249
26	8 32 a.m. to 9 11 a.m...	240	233	...	...	...	...	237
31	8 35 a.m. to 9 44 a.m...	235	241	244	...	...	...	240
Feb. 1	8 46 a.m. to 9 26 a.m...	...	239	242	...	...	...	241
2	8 40 a.m. to 9 43 a.m...	243	247	247	...	...	...	246
6	8 47 a.m. to 11 50 a.m...	...	243	233	225	234	[2]231	[2]233
7	8 35 a.m. to 9 36 a.m...	236	232	231	...	...	...	233
8	8 36 a.m. to 9 31 a.m...	260	254	254	...	...	...	256
9	8 38 a.m. to 9 39 a.m...	244	237	246	...	...	...	242
13	8 38 a.m. to 9 43 a.m...	234	235	230	...	...	...	233
14	8 36 a.m. to 9 39 a.m...	239	232	233	...	...	...	235
15	8 38 a.m. to 9 36 a.m...	234	228	240	...	...	...	234
16	8 40 a.m. to 9 40 a.m...	220	223	222	...	...	...	222
20	8 46 a.m. to 9 49 a.m...	243	250	250	...	...	...	248
21	8 39 a.m. to 9 44 a.m...	243	232	233	...	...	...	236
23	8 42 a.m. to 9 43 a.m...	229	234	243	...	...	...	235
26	8 41 a.m. to 9 45 a.m...	229	245	243	...	...	...	239
27	8 40 a.m. to 9 42 a.m...	242	241	235	...	...	...	239
29	8 41 a.m. to 9 41 a.m...	253	257	265	...	...	...	258
Mar. 6	8 47 a.m. to 10 01 a.m...	...	261	257	258	...	...	259
11	8 44 a.m. to 9 22 a.m...	...	245	248	...	...	...	247
20	12 45 p.m. to 2 02 p.m...	...	...	...	...	...	...	[3]240
22	8 22 a.m. to 10 35 a.m...	255	245	254	249	248	...	250
26	8 43 a.m. to 9 42 a.m...	232	235	232	...	...	...	233
29	8 43 a.m. to 9 50 a.m...	277	283	269	282	...	...	278
Apr. 16 1914.	8 38 a.m. to 9 34 a.m...	249	238	250	...	...	...	246
Apr. 18	8 24 a.m. to 10 03 a.m...	226	229	229	232	...	...	229
	Days.....	43	48	40	10	4	2	[4]54
	Minimum.....	220	217	222	225	234	231	222
	Maximum.....	277	283	269	282	257	238	278
	Average.....	242	242	241	246	246	235	242
	M. V.....	11.0	10.1	9.9	16.3	7.0	3.5	9.7

[1]The experimental periods were usually 15 minutes in length and there was but one period in each half hour.

[2]Two other results (seventh period, 231 c.c., and eighth period, 231 c.c.) were obtained and included in the average for the day.

[3]Average of results obtained in ninth to twelfth periods, 246, 235, 236, and 241 c.c., respectively.

[4]The total number of periods in which the oxygen was determined in the 54 experiments was 153.

GENERAL DETAILS REGARDING THE RESEARCH.

The experiments in 1905, 1906, and 1907, included in this research on the effect upon the metabolism of the ingestion of food, were made at Wesleyan University, Middletown, Connecticut, and those subsequent to 1907 in the Nutrition Laboratory in Boston. Only the respiration calorimeter was used in the Middletown experiments. In the Boston experiments not only the chair and bed respiration calorimeters were employed, but also two forms of respiration apparatus—*i. e.*, the universal respiration apparatus and the Tissot respiration apparatus. With the calorimeters, the carbon-dioxide production, the oxygen consumption, and the heat production were determined; with the respiration apparatus, determinations were made only of the respiratory exchange, the heat production being obtained by indirect calorimetry. The several apparatus have been fully described elsewhere; brief descriptions are included in this publication.[1] The general plan of experimenting has been given in the preceding section; the routine with the various apparatus has also been outlined with more or less detail in the discussion of the results of the experiments.

In the Middletown calorimeter considerable freedom of movement was possible. In the 24-hour experiments with this apparatus the subject was able to carry out the ordinary routine of a day, restricted only by the confines of the chamber and the experimental requirements for a minimum amount of activity. In the waking hours he sat in a chair; in the sleeping periods he lay on the bed. During the 8-hour experiments with the same apparatus he sat quietly in a chair. In the chair calorimeter in Boston the subject also sat in a chair for the entire experimental period and was instructed to reduce all movement to the minimum. In all these apparatus the water and urine vessels and telephone were placed conveniently near the subject, so that they could be used with the least activity possible. In the bed calorimeter the subject lay on an air mattress with few or no major changes of position. In the experiments with the two respiration apparatus the subject lay on a couch, practically without movement, during the periods.

In the Middletown calorimeter experiments the individual periods were usually 2 hours in length; in the Boston calorimeter experiments they were shortened to 1 hour and in a few instances to 45 minutes. With the universal respiration apparatus the periods ordinarily approximated 15 minutes in length; with the Tissot apparatus the periods were generally shorter. The observations in the experiments with the two

[1]For a description of the Middletown calorimeter, see Atwater and Benedict, Carnegie Inst. Wash. Pub. No. 42, 1905. For the chair and bed calorimeters, see Benedict and Carpenter, Carnegie Inst. Wash. Pub. No. 123, 1910. For the universal respiration apparatus, see Benedict, Deutsch. Arch. f. klin. Med., 1912, **107**, p. 156; Carpenter, Carnegie Inst. Wash. Pub. No. 216, 1915. For the Tissot respiration apparatus, see Tissot, Journ. de physiol. et de path. gén., 1904, **6**, p. 688, and Carpenter, Carnegie Inst. Wash. Pub. No. 216, 1915, p. 61.

respiration apparatus were not continuous, there being intermissions varying in length according to the conditions of experimenting, food material used, etc. It was usual to make a 15-minute observation every half hour during the experimental period, but the intermissions were often much longer. The intermissions with the Tissot apparatus were usually brief. As a rule, the subject lay on the couch during the intermissions with both apparatus and was more or less quiet.

In the Middletown experiments the movements made by the subject were recorded by an observer, but in nearly all of the Boston experiments the degree of muscular repose was shown by some form of graphic record. In many of the calorimeter experiments observations were made of the body-temperature; the data recorded were secured per rectum, by means of an electrical-resistance thermometer.

Records of the pulse rate were obtained with the Fitz pneumograph in the Middletown experiments, but in the calorimeter experiments in Boston and in the experiments with respiration apparatus the Bowles stethoscope was used, the counts being made by a special observer.

Records of the respiration rate were secured in practically all of the Middletown and Boston calorimeter experiments and in the experiments with the tension-equalizer form of the universal respiration apparatus by means of the Fitz pneumograph. In the experiments with the respiration apparatus the pneumograph was connected with a kymograph, thus giving graphic records of the respiration. In the observations with the spirometer form of the universal respiration apparatus, the graphic record of the respiration was provided by a mechanical device attached to the spirometer instead of by the Fitz pneumograph.

In several groups of the Boston experiments, *i. e.*, those with water, coffee, and beef tea, records of the blood pressure were obtained with the Erlanger sphygmomanometer.

Table 49 gives a list of the food experiments, grouped according to the apparatus and diet used. It shows that 59 experiments were made with the respiration calorimeter in Middletown, 41 experiments with the chair calorimeter and 3 experiments with the bed calorimeter in Boston. In the experiments in which only the respiratory exchange was determined, 78 experiments were made with the universal respiration apparatus and 9 experiments with the Tissot apparatus. The research included, in all, 190 experiments, *i. e.*, 15 chewing experiments, 11 experiments with water, 8 with coffee, 13 with beef tea, 65 with carbohydrates, 15 with a fat diet, 44 with a protein diet, and 19 with mixed nutrients.

The composition and fuel value of the food materials used in the experiments are shown in table 50. The values are, for the most part, directly determined or are computed from determined values. The composition of the mixed diets may be found in the section describing the experiments with mixed nutrients.[1]

[1]See table 235, p. 310.

TABLE 49.—*Summary of experiments following the ingestion of food.*

Kind of experiment.	Middletown calorimeter.	Boston.				Total
		Calorimeter.		Universal respiration apparatus.	Tissot respiration apparatus.	
		Chair.	Bed.			
Chewing	3	4	1	7	..	15
Water	2	3	..	6	..	11
Coffee	2	..	..	6	..	8
Beef tea	5	2	..	6	..	13
Carbohydrates:						
Dextrose	..	..	..	13	1	14
Levulose	..	..	..	8	1	9
Sucrose	2	2	..	14	1	19
Lactose	..	..	..	4	1	5
Maltose-dextrose mixture	4	1	..	..	..	5
Bananas and sugar	5	2	..	..	..	7
Bananas	..	3	..	..	..	3
Popcorn	2	..	..	..	..	2
Rice (boiled)	1	..	..	..	..	1
Fat:						
Mayonnaise	1	..	..	..	..	1
Cream	3	4	..	..	..	7
Butter and potato chips	4	3	..	..	..	7
Protein:						
Beefsteak (cooked)	4	5	..	11	4	24
Beefsteak and bread	..	3	..	..	..	3
Beefsteak and potato chips	..	4	1	1	..	6
Glidine	..	5	..	..	..	5
Gluten and skim milk	4	..	..	..	..	4
Plasmon and skim milk	2	..	..	..	..	2
Mixed nutrients:						
Milk	3	..	..	1	..	4
Mixed diet	[1]12	..	1	1	1	15
Total	59	41	3	78	9	190

[1]These include 6 heavy-breakfast and 2 heavy-supper experiments.

Statistical data for the subjects of the experiments following the ingestion of food are given in table 51. In all there were 39 male subjects, the average age for the period of experimenting ranging from 17 to 48 years. The large majority of the subjects were from 20 to 30 years of age. The average body-weight without clothing ranged from 48 to 83 kilograms. The greater number of the subjects had a body-weight between 55 and 65 kilograms.

The experiments with each class of nutrients are discussed in separate chapters in the following pages. In the tabulated results for the calorimeter experiments, the amount, nitrogen content, and total energy of the diet are given, also the fuel value, and the proportions of energy from the different nutrients. The basal values for the carbon-dioxide production, oxygen consumption, and heat production are likewise recorded, together with the basal nitrogen in the urine of the experimental day if this was obtained. Whenever the respiratory quotients are given for the food periods, the basal respiratory quotient,

TABLE 50.—*Percentage composition of food materials used in experiments.*[1]

Food material.	Protein.	Fat.	Carbohydrates.	Fuel value per gram.	Remarks.
	p. ct.	*p. ct.*	*p. ct.*	*cals.*	
Bananas	1.3[2]	0.6[2]	22.0[2]	1.014[2]	
Beefsteak (cooked)	22.9	5.4[3]	.....	1.441[4]	Analyzed for J. R., Dec. 4, 1908.
Do	31.2	14.5[4]	.....	2.630	Analyzed for A. W. W., May 25, 1907.
Do	28.7[5]	5.4[5]	.....	1.679[4]	
Beef tea	1.3[6]	0.1[2]	0.2[2]	0.072[4]	Used for A. W. W., May 2, 1907.
Do.	2.5[7]	0.1[2]	0.2[2]	0.118[4]	
Bread, black	9.6	0.3	48.9[2]	2.427[4]	
Bread, gluten[8]	89.4	0.3	4.8	4.195	
Bread, white	9.7[9]	1.3[2]	53.1[2]	2.694[4]	
Butter	1.0[2]	85.0[2]	.....	8.090[9]	
Coffee	0.5	.....	2.7	0.131[4]	Analyzed for J. J. C., Mar. 9, 1911.[10]
Do.	0.2[9]	.....	1.0[9]	0.050[4]	
Cream	2.7[11]	20.4[4]	4.5[2]	2.189[11]	Used for H. R. D., Mar. 28, 1906.
Do	2.4	29.8	4.5[2]	3.060[4]	Analyzed for J. J. C., Mar. 22, 1910.
Do	2.4	25.6	4.5[2]	2.664[4]	Analyzed for D. J. M., June 3, 1910.
Do	2.2	32.7	4.5[2]	3.312[4]	Analyzed for D. J. M., June 7, 1910.
Do	2.4[12]	29.4[12]	4.5[2]	3.012[4]	Used for D. J. M., Mar. 23, 1910.
Dextrose[13]	....	.....	100.0	3.739	
Glidine	86.6	0.7	3.0[4]	3.739[4]	
Lactose[13]	.....	.....	100.0	3.737	
Lemon juice	.....	.....	2.3[14]	0.280[4]	
Lettuce	1.2[2]	0.3[2]	2.9[2]	0.198[2]	
Levulose[13]	.....	.....	100.0	3.729	
Maltose-dextrose mixture	.....	.....	([15])	3.018	
Mayonnaise	1.1[4]	86.4[4]	0.2[4]	8.197	
Milk, skim	3.2[9]	0.3[2]	5.1[2]	0.346[9]	
Milk, whole	3.3[2]	4.0[2]	5.0[2]	0.716[2]	
Plasmon	74.5	0.2	6.9	3.786	
Plasmon, graham biscuit	14.3	10.0[16]	69.2[4]	4.355	
Plasmon, milk biscuit	18.7	10.0[16]	65.0[4]	4.363	
Popcorn	10.9	5.0[2]	78.7[2]	4.255	
Potato chips	5.5[17]	39.8[2]	46.7[2]	5.604[9]	Used for E. H. B., A. H. M., and A. W. W.
Do	4.8	37.6	39.6	5.316[4]	Analyzed for J. J. C., Mar. 12, 1910.
Do	3.0	52.5	42.1[9]	6.734[4]	Analyzed for L. E. E., Mar. 14, 1910.
Do	4.7	39.2	38.2	5.402[4]	Analyzed for J. R., Mar. 21, 1910.
Do	4.2[18]	37.7[18]	42.1[18]	5.402[4]	
Rice (boiled)	1.9	0.1[2]	14.0[4]	0.662	
Sucrose	.....	.....	100.0	3.960	

[1]For composition of mixed diets used in the research see table 235, p. 310.
[2]Atwater and Bryant, U. S. Dept. Agr., Office Exp. Stas. Bull. 28, 1906.
[3]Average value excluding that for A. W. W., May 25, 1907. [4]Computed.
[5]Average value; when available actual determinations substituted for average and fuel values recomputed.
[6]Average of determinations for E. H. B., Apr. 8, 1907, and A. H. M., Apr. 29, 1907, with whom the actual determinations of protein were used and fuel values computed accordingly. For data regarding creatinine and creatine, see pp. 160 and 161.
[7]Average of determinations obtained in experiments other than those with E. H. B. and A. H. M. Actual determinations used when available and fuel values recomputed.
[8]Benedict, Carnegie Inst. Wash. Pub. No. 77, 1907, p. 203; in calculating protein from nitrogen the usual factor, 6.25, was used. [9]Average value; determined values substituted when available.
[10]Also used for Prof. C. Nov. 20 and Nov. 22, 1909, in experiments with sucrose.
[11]Average of determinations obtained for A. L. L. and A. H. M., with whom the actual determinations of protein and energy were used.
[12]Average value, not including determinations used in first average for cream.
[13]Emery and Benedict, Am. Journ. Physiol., 1911, 28, p. 301.
[14]Also 7.5 p. ct. citric acid. Atwater and Bryant, *loc. cit.*
[15]Four analyses made elsewhere on samples of this product show on the average 39 p. ct. of maltose, 27 p. ct. of dextrose and 34 p. ct. of water.
[16]Assumed. [17]Determined on sample for A. W. W., Apr. 25, 1907.
[18]Average of all values obtained for potato chips, excepting those included in first average; determined values substituted when available and fuel values recomputed.

TABLE 51.—*Statistics of age, height, and weight of subjects used in experiments following the ingestion of food.*

Subject.	Occupation.	Average age.	Height.	Average body-weight without clothing.
Middletown:		*years.*	*cm.*	*kilos.*
E. H. B.	College student	23	174	73
H. R. D.	Do	18	171	58
H. C. K.	Do	22	181	74
A. L. L.	Do	25 26	166	68[1] 74[1]
A. H. M.	Do	25	179	66
N. M. P.	Do	22	177	65
Dr. R.	Physician	26	168	50
A. W. W.	College student	23	173	58
D. W.	Do	22	180	76
H. B. W.	Do	20	162	62
Boston:				
H. H. A.	Medical student	21	164	62
K. H. A.	Laboratory assistant	26	182	66
F. G. B.	Chemist	40	183	83
J. C. C.	College student	22	173	55
J. J. C.	Laboratory assistant	27	175	64
J. P. C.	Medical student	23	169	73
Prof. C.	Physiologist	36	169	83
T. M. C.	Chemist	32	166	48
A. G. E.	Do	26	169	57
H. G. E.	Tinsmith	21	183	65
L. E. E.	Chemist	31	175	60
A. F.	Student	25	175	66
A. F. G.	Laboratory assistant	24	175	54
V. G.	Do	17	162	55
C. H. H.	Do	19	169	55
Dr. H.	Professor	48	182	66
H. L. H.	Chemist	24	172	60
P. F. J.	Laboratory assistant	20	167	57
B. M. K.	Medical student	27	163	51
D. M.	Do	22	171	63
D. J. M.	Laboratory assistant	20	175	58
F. M. M.	Do	17	173	61
J. F. M.	College student	20	181	77
J. K. M.	Laboratory assistant	23	173	61
A. J. O.	Baseball player	30	180	69
Dr. P. R.	Physician	41	164	55
J. R.	Chemist	27	182	69
Dr. S.	Professor	43	181	59
H. F. T.	Dental student	32	179	58

[1]For years 1906 and 1907, respectively, because of marked difference in physical characteristics of subject.

i. e., that obtained on the same day, is recorded for comparison. The period between the time the subject finished eating and the beginning of each experimental period after food is shown, also the total amount and the increase over the basal value for each of the three factors of metabolism (carbon-dioxide production, oxygen consumption, and heat production); the respiratory quotients are included in the tables only

when significant. If available, the nitrogen in the urine excreted during the food periods is given, either as an average figure with the food data at the head of the table or for the individual periods in a separate column.

The tables for the respiration experiments give the data for the diet, also the average basal values per minute for the gaseous exchange, the computed heat production, the respiration rate, and the pulse rate. The time of beginning each period of measurement after food and the results of the observations are shown, with the addition in some cases of the values for the inspiratory ventilation. While the increments in the metabolism have not been calculated, they are readily noted by a comparison of the average basal values with the data recorded for each period following the ingestion of food. The time when the food was taken is given in a footnote. In both the calorimeter and respiration experiments the subjects usually ate the food in 15 or 20 minutes; if longer than this was required, the time thus occupied is stated in a footnote.

METABOLISM DURING CHEWING.

Of the various processes classified by Professor Armsby[1] as prior to actual digestion, the work of prehension is hardly suitable for experimental study, since it would vary greatly with different individuals and with the different kinds of food consumed. On the other hand, mastication is a physiological function accompanying all ingestion of food. Indeed, a cult with many adherents has been established to advocate prolonged mastication. Hence information regarding the probable energy transformations as a result of mastication has unusual interest. To study this question, a series of experiments was made in which the subject chewed gum for a considerable length of time. This study was supplemented by a second series of experiments in which a rubber stopper was substituted for the chewing gum.

STATISTICS OF EXPERIMENTS.

The calorimeter experiments included 3 experiments with the respiration calorimeter at Middletown, Connecticut (tables 52 to 54), 4 with the chair calorimeter (tables 55 and 57 to 59) and 1 with the bed calorimeter in Boston, Massachusetts (table 56). In all of these the subject chewed gum. In addition, 5 respiration experiments were made with the subject chewing gum (tables 60 to 64) and two respiration experiments in which a rubber stopper was chewed vigorously (tables 65 and 66). A summary of the values obtained for the heat production in these experiments is included in tables 67 and 68.

[1]Armsby, The principles of animal nutrition, 2d ed., 1906, p. 374.

For the respiration experiments the output of heat was computed by the indirect method. These experiments consisted of two series of periods, in the first of which the subject was without food and did no chewing. As the measurements of the metabolism were not continuous, it was necessary to compute the values given in tables 67 and 68 for the total increment due to chewing by the best method obtainable and to make certain assumptions.

Tables 60 to 66 show both the average heat production for the periods without food or chewing, *i. e.*, the basal value for the day, and the heat output for each of the periods with chewing. The increase in the metabolism in the periods with chewing has been obtained by comparing the basal value for the day with the heat computed for each period. These increments of heat represent the results of two to four periods in which the metabolism was measured. The total time of chewing in the several respiration experiments varied from 53 minutes to 2 hours 19 minutes; the total duration of the measurement of the metabolism (not continuous) was from 30 to 60 minutes. In computing the total increment in the metabolism due to chewing (see table 68), it was assumed that the increase was coincident with the beginning of chewing. It was furthermore assumed that the rate of increase in the periods between the beginning of chewing and the beginning of the measurements (6 to 14 minutes), also in the intervals between the periods of measurement (6 to 40 minutes), was the same as that in the measured periods and that the average increment obtained for these periods represents the rate of increase in the metabolism for the total time of observation—*i. e.*, from the beginning of chewing to the end of the last period. The total increment in the metabolism for this time was therefore computed by direct proportion.

For example, in the experiment with V. G., January 5, 1911 (see table 62, page 133), the average basal value for the heat output per minute obtained in periods without food and without the work of chewing, was 1.13 calories. The subject began chewing 10 minutes before the measurements of the metabolism commenced. The values obtained for the respective chewing periods were 1.46, 1.52, 1.43, and 1.32 calories for a total period of measurement of 53 minutes. The average increment in the metabolism during the measured periods of chewing was therefore 0.30 calorie per minute. Using this value and the total time of chewing, that is, the period from 11^h11^m a. m. to 1^h30^m p. m., or 2 hours 19 minutes, the total increase in the metabolism (139×0.30) was computed to be 42 calories. The basal value corresponding to this period (139 by 1.13) was 157 calories. The percentage increase in the metabolism ($42 \div 157$) was therefore 27 per cent.

Statistical data not included in the tables or in the discussion are given for all of the experiments in the following paragraphs. The data for pulse rate and respiration rate represent averages of the indi-

vidual records for the basal and chewing periods. Records of the body-temperature, when available, were made with the rectal thermometer at the beginning of the periods and at the end of the experiment. Analyses of chewing gum give 62 to 69 per cent of soluble carbohydrates. When the basal values were determined immediately before the chewing periods, the times given include both basal and chewing periods.

CALORIMETER EXPERIMENTS.

A. L. L., 8h40m a.m. to 4h40m p. m., April 3, 1906. 67.6 kilograms.—Urinated at 4h42m and 7 p. m. Studied most of time and very quiet. Chewed rapidly and regularly. Basal periods: body-temperature, 36.69° and 36.59° C.; pulse rate, 57; respiration rate, 18. Chewing periods: body-temperature, all records, 36.65° C.; pulse rate, 58; respiration rate, 19.

H. R. D., 8h37m a. m. to 4h37m p. m., April 4, 1906. 58.2 kilograms.—Urinated at 7h15m a. m. (after enema) and 4h48m p. m. Sat quietly reading. Rate of chewing, 72 to 107 per minute, first chewing period; 81 to 85 per minute, second chewing period. Basal periods: body-temperature, 36.73° and 36.67° C.; pulse rate, 69; respiration rate, 18. Chewing periods: body-temperature, 36.63°, 36.76°, and 36.76° C.; pulse rate, 69; respiration rate, 19.

H. B. W., 8h05m a. m. to 4h05m p. m., April 26, 1907. 62.6 kilograms.—Urinated and defecated without enema before coming to laboratory. Very quiet in first basal period, but less quiet in second period; increasingly restless in chewing periods. Chewed steadily most of time; rate 64 to 96 per minute. Basal periods: body-temperature, 36.83° and 36.68° C.; pulse rate, 64; respiration rate, 18. Chewing periods: body-temperature, 36.74°, 36.75°, and 36.76° C.; pulse rate, 66; respiration rate, 18.

J. J. C., 8h14m a. m. to 12h14m p. m., March 25, 1910. 64.8 kilograms.—Urinated 5h30m a. m., 8h35m a. m., and 12h35m p. m. Reported asleep 9h08m, 9h20m, and 9h40m a. m. Basal periods: pulse rate, 60; respiration rate, 18. Chewing periods: pulse rate, 63; respiration rate, 19.

V. G., 9h12m a. m. to 2h04m p. m., December 19, 1910. 55 kilograms.—In bed calorimeter. Was quiet throughout experiment except for turning over at beginning of second basal and last two chewing periods; had to be awakened several times in second basal period, but awake most of third basal period. Complained of being warm, but temperature of chamber did not exceed 21° C. at any time. Basal periods: pulse rate, 69; respiration rate, 21. Chewing periods: pulse rate, 79; respiration rate, 22.

V. G., 9h07m a. m. to 12h15m p. m., January 2, 1911. 56.3 kilograms.—Very quiet at beginning of basal periods, but most of experiment restless; very restless in last chewing period, owing to pain in stomach. Basal periods: pulse rate, 62; respiration rate, 20. Chewing periods: pulse rate, 63; respiration rate, 19.

T. M. C., 8h25m a. m. to 11h28m a. m., January 3, 1911. 47.7 kilograms.—Urinated at 7h15m a. m. Read quietly. Rate of chewing approximately two movements of jaws a second. Basal periods: pulse rate, 68; respiration rate, 15. Chewing periods: pulse rate, 77; respiration rate, 17.

T. M. C., 8h43m a. m. to 12h30m p. m., January 7, 1911. 48 kilograms.—Urinated 6h45m a. m. and 1h44m p. m. Very quiet throughout experiment. Rate of chewing, 100 to 106 in first chewing period and 88 to 100 in second chewing period. Basal periods: pulse rate, 68; respiration rate, 15. Chewing periods: pulse rate, 78; respiration rate, 16.

TABLE 52.—*A. L. L., April 3, 1906. Sitting.*

Chewing gum (15 grams). Nitrogen in urine, 0.65 gram[1] per 2 hours.
Basal values per 2 hours (April 3, 1906): CO_2, 49 grams; O_2, 43 grams; heat, 147 cals.

Period (duration of chewing).	Carbon dioxide.		Oxygen.		Heat.	
	Total.	Increase.	Total.	Increase.	Total.	Increase.
	grams.	*grams.*	*grams.*	*grams.*	*cals.*	*cals.*
2 hours	56	7	47	4	153	6
2 hours	53	4	47	4	158	11
Total (4 hrs.)	109	11	94	8	311	17
Basal values	98	..	86	..	294	..

[1]Sample included amount for about $7\frac{3}{4}$ hours, without food, preceding and following the periods of chewing.

TABLE 53.—*H. R. D., April 4, 1906. Sitting.*

Chewing gum (15 grams). Nitrogen in urine, 0.52 gram[1] per 2 hours.
Basal values per 2 hours: CO_2, 46 grams (Apr. 4, 1906); O_2, 42 grams (Feb. 6 to Apr. 20, 1906); heat, 148 cals. (Apr. 4, 1906).

Period (duration of chewing).	Carbon dioxide.		Oxygen.		Heat.	
	Total.	Increase.	Total.	Increase.	Total.	Increase.
	grams.	*grams.*	*grams.*	*grams.*	*cals.*	*cals.*
2 hours	51	5	44	2	151	3
2 hours	48	2	41	−1	142	−6
Total (4 hours)	99	7	85	1	293	−3
Basal values	92	..	84	..	296	..

[1]Sample included amount for about $5\frac{1}{4}$ hours, without food, preceding the periods of chewing.

TABLE 54.—*H. B. W., April 26, 1907. Sitting.*

Chewing gum (30 grams). Nitrogen in urine, 0.87 gram[1] per 2 hours.
Basal values per 2 hours (Apr. 26, 1907): CO_2, 57 grams; O_2, 50 grams; heat, 166 cals.

Period (duration of chewing).	Carbon dioxide.		Oxygen.		Heat.	
	Total.	Increase.	Total.	Increase.	Total.	Increase.
	grams.	*grams.*	*grams.*	*grams.*	*cals.*	*cals.*
1 hour 51 minutes	54[2]	1	47[2]	1	154[2]	0
2 hours	57	0	51	1	171	5
Total (3 hrs. 51 min.)	111	1	98	2	325	5
Basal values	110	..	96	..	320	..

[1]Sample included amount for about $5\frac{1}{2}$ hours, without food, preceding the periods of chewing.
[2]Computed from result for actual period of 2 hours by deducting basal value equivalent to 9 minutes at beginning of experiment when subject was not chewing.

TABLE 55.—*J. J. C., March 25, 1910. Sitting.*

Chewing gum.[1] Nitrogen in urine, 0.49 gram[2] per hour.
Basal values per hour (Mar. 25, 1910): CO_2, 25.5 grams; O_2, 21 grams; heat,[3] 79 cals.; respiratory quotient, 0.88. Nitrogen in urine, 0.30 gram per hour.

Period (duration of chewing).	Carbon dioxide.		Oxygen.		Heat.[3]		Respiratory quotient.
	Total.	Increase.	Total.	Increase.	Total.	Increase.	
	grams.	*grams.*	*grams.*	*grams.*	*cals.*	*cals.*	
48 minutes	23.5[4]	3.0	20.5[4]	3.5	64[4]	1	0.85
60 minutes	28.0	2.5	22.5	1.5	77	−2	.90
Total (1 hr. 48 min.)	51.5	5.5	43.0	5.0	141	−1	....
Basal values	46.0	...	38.0	...	142	..	....

[1]Amount not recorded.
[2]Sample included amount for $1\frac{3}{4}$ hours, without food, preceding the periods of chewing.
[3]Heat eliminated corrected for change in body-weight, but not for change in body-temperature.
[4]Computed from result for actual period of 1 hour by deducting basal value equivalent to 12 minutes at beginning of experiment when subject was not chewing.

TABLE 56.—*V. G., December 19, 1910. Lying.*

Chewing gum.[1] Nitrogen in urine, 0.32 gram[2] per hour.
Basal values per hour (Dec. 19, 1910): CO_2, 25.5 grams; O_2, 22 grams; heat,[3] 67 cals.; respiratory quotient, 0.85.

Period (duration of chewing).	Carbon dioxide.		Oxygen.		Heat.[3]		Respiratory quotient.
	Total.	Increase.	Total.	Increase.	Total.	Increase.	
	grams.	*grams.*	*grams.*	*grams.*	*cals.*	*cals.*	
32 minutes	14.5[4]	1.0	11.5[4]	0.0	41[4]	5	0.90
45 minutes	20.5	1.5	16.5	0.0	54	4	.89
67 minutes	31.0	2.5	28.0	3.5	92	17	.81
Total (2 hrs. 24 min.)	66.0	5.0	56.0	3.5	187	26	....
Basal values	61.0	...	52.5	...	161	..	....

[1]Amount not recorded.
[2]Sample included amount for 4 hours, without food, preceding the periods of chewing.
[3]Heat eliminated corrected for change in body-weight, but not for change in body-temperature.
[4]Computed from result for actual period of 45 minutes by deducting basal value equivalent to 13 minutes at beginning of experiment when subject was not chewing.

TABLE 57.—*V. G., January 2, 1911. Sitting.*

Chewing gum (about 6 grams). Nitrogen in urine, 0.39 gram[1] per 45 minutes.
Basal values per 45 minutes (January 2, 1911): CO_2, 22.5 grams; O_2, 19 grams; heat,[2] 62 cals.; respiratory quotient, 0.87.

Period (duration of chewing).	Carbon dioxide.		Oxygen.		Heat.[2]		Respiratory quotient.
	Total.	Increase.	Total.	Increase.	Total.	Increase.	
	grams.	*grams.*	*grams.*	*grams.*	*cals.*	*cals.*	
45 minutes	21.5	−1.0	19.5	0.5	63	1	0.80
45 minutes	22.5	0.0	17.5	−1.5	60	−2	.93
Total (1 hr. 30 min.)	44.0	−1.0	37.0	−1.0	123	−1	....
Basal values	45.0	...	38.0	...	124	..	....

[1]Sample included amount for about 3 hours, without food, preceding and following the periods of chewing.
[2]Heat eliminated corrected for change in body-weight, but not for change in body-temperature.

TABLE 58.—*T. M. C., January 3, 1911. Sitting.*

Chewing gum.[1] Nitrogen in urine, 0.27 gram[2] per 45 minutes.
Basal values per 45 minutes (January 3, 1911): CO_2, 14 grams; O_2, 13 grams; heat,[3] 47 cals.; respiratory quotient, 0.79.

Period (duration of chewing).	Carbon dioxide.		Oxygen.		Heat.[3]		Respiratory quotient.
	Total.	Increase.	Total.	Increase.	Total.	Increase.	
	grams.	*grams.*	*grams.*	*grams.*	*cals.*	*cals.*	
38 minutes	14.5[4]	2.5	11.0[4]	0.0	41[4]	1	0.94
45 minutes	17.5	3.5	14.5	1.5	50	3	.88
Total (1 hr. 23 min.)	32.0	6.0	25.5	1.5	91	4	....
Basal values	26.0	...	24.0	...	87	..	....

[1]Amount not recorded.
[2]Sample included amount for about 2¾ hours, without food, preceding the periods of chewing.
[3]Heat eliminated corrected for change in body-weight, but not for change in body-temperature.
[4]Computed from result for actual period of 45 minutes by deducting basal value equivalent to 7 minutes at beginning of experiment when subject was not chewing.

TABLE 59.—*T. M. C., January 7, 1911. Sitting.*

Chewing gum.[1] Nitrogen in urine, 0.19 gram[2] per 45 minutes.

Basal values per 45 minutes (January 7, 1911): CO_2, 14 grams; O_2, 12.5 grams; heat,[3] 42 cals.; respiratory quotient, 0.80.

Period (duration of chewing).	Carbon dioxide.		Oxygen.		Heat.[3]		Respiratory quotient.
	Total.	Increase.	Total.	Increase.	Total.	Increase.	
	grams.	*grams.*	*grams.*	*grams.*	*cals.*	*cals.*	
38 minutes	14.0[4]	2.0	11.5[4]	1.0	36[4]	1	0.87
45 minutes	17.0	3.0	15.0	2.5	48	6	.82
Total (1 hr. 23 min.)	31.0	5.0	26.5	3.5	84	7	....
Basal values	26.0	...	23.0	...	77	..	....

[1]Amount not recorded.

[2]Sample included amount for about 5½ hours, without food, preceding and following the periods of chewing.

[3]Heat eliminated corrected for change in body-weight, but not for change in body-temperature.

[4]Computed from result for actual period of 45 minutes by deducting basal value equivalent to 7 minutes at beginning of experiment when subject was not chewing.

RESPIRATION EXPERIMENTS.

T. M. C., 12 noon to 12^{h}50^m p. m., December 17, 1910.—Light breakfast at 7^{h}30^m a. m. (two small slices toasted and buttered white bread and cupful of coffee, with cream and sugar). Rate of chewing, 68 to 86 per minute in first period, 74 to 87 per minute in second period; difficult for subject to keep mouth closed when chewing.

J. J. C., 9^{h}27^m a. m. to 1^{h}55^m p. m., January 4, 1911. 64.6 kilograms.—Head confined in wooden head-rest to prevent its moving out of position during sleep. Slept a few minutes in first basal period and nearly all of third basal period. Adhesive plaster over lips in basal periods. Rate of chewing, 80 to 92 per minute; in second chewing period, stopped chewing once and opened mouth for about 3 seconds. Nitrogen in urine per hour, 8 a. m. to 5^{h}10^m p. m., 0.37 gram.

V. G., 8^{h}35^m a. m. to 1^{h}30^m p. m., January 5, 1911. 56 kilograms.—Asleep in second basal period; second chewing period shortened to 7 minutes, as subject was dizzy and had some difficulty in breathing; also dizzy last two minutes of third chewing and at end of fourth chewing periods. Rate of chewing, 46 to 75 per minute. Urinated at 7^{h}50^m a. m. and urinated and defecated at 2^{h}40^m p. m. Nitrogen in urine per hour, 7^{h}50^m a. m. to 2^{h}40^m p. m., 0.33 gram.

F. G. B., 8^{h}10^m a. m. to 10^{h}05^m a. m., January 9, 1911. 83.5 kilograms.—Urinated at 7^{h}44^m a. m., 8^{h}28^m a. m., and 9^{h}24^m a. m. Rate of chewing, 93 to 103 per minute in first chewing period, 100 to 104 per minute in second chewing period.

F. G. B., 11^{h}03^m a. m. to 11^{h}45^m a. m., May 5, 1911. Chewing periods followed water-drinking experiment of same date (see table 79, page 147); for data regarding basal period, see statistics for that experiment. Chewed with mouth closed; rate of chewing, 90 to 95 per minute in first period and 112 to 114 per minute in second period. Nitrogen in urine per hour, 10^{h}54^m a. m. to 11^{h}47^m a. m., 0.41 gram.

V. G., 11^{h}26^m a. m. to 12^{h}31^m p. m., January 31, 1911. 54.9 kilograms.—Chewing periods followed water-drinking experiment of same date (see table

74, page 146); for data regarding basal periods, see statistics for that experiment. Opened mouth several times during chewing. Nitrogen in urine per hour 7^h45^m a. m. to 12^h50^m p. m., 0.32 gram.

J. J. C., 1^h03^m p. m. to 2^h09^m p. m., February 7, 1911. 63.9 kilograms.—Chewing periods followed water-drinking experiment of same date (see table 75, page 146); for data regarding basal periods, see statistics for that experiment. Nitrogen in urine per hour, 7^h30^m a. m. to 2^h16^m p. m., 0.41 gram.

TABLE 60.—*T. M. C., December 17, 1910. Chewing gum (6 grams). Lying.* (Values per minute.)

Basal values (Nov. 14 and 16, 1910): CO_2, 163 c.c.; O_2, 187 c.c.; heat (computed), 0.91 cal.; average pulse rate, 72; average respiration rate, 13.

Time.	Average respiration rate.	Carbon dioxide.	Respiratory quotient.	Oxygen.	Average pulse rate.	Heat (computed).
		c.c.		*c.c.*		*cals.*
Chewing gum:[1]						
12 noon	16	177	0.84	210	69	1.02
12^h35^m p.m.	15	171	.80	213	70	1.02

[1]Subject began chewing at 11^h50^m a. m.

TABLE 61.—*J. J. C., January 4, 1911. Chewing gum (9 grams). Lying.* (Values per minute.)

Time.	Average respiration rate.	Carbon dioxide	Respiratory quotient.	Oxygen.	Average pulse rate.	Heat (computed).
		c.c.		*c.c.*		*cals.*
Without food:						
Av. of 3 periods	16	201	0.93	217	63	1.08
Chewing gum:[1]						
12^h21^m p.m.	17	239	....	...	70	1.30
12 47 p.m.	18	228	....	...	69	1.24
1 08 p.m.	19	230	....	...	72	1.25
1 40 p.m.	19	231	....	...	69	1.25

[1]Subject began chewing at 12^h07^m p. m.

TABLE 62.—*V. G., January 5, 1911. Chewing gum.*[1] *Lying.* (Values per minute.)

Time.	Average respiration rate.	Carbon dioxide.	Respiratory quotient.	Oxygen.	Average pulse rate.	Heat (computed).
		c.c.		*c.c.*		*cals.*
Without food:						
Av. of 3 periods	20	205	0.90	229	59	1.13
Chewing gum:[2]						
11^h21^m a.m.	17	269	....	...	88	1.46
11 51 a.m.	18	281	....	...	84	1.52
12 19 p.m.	18	263	....	...	86	1.43
1 15 p.m.	19	243	....	...	77	1.32

[1]Amount not recorded.

[2]Subject began chewing at 11^h11^m a. m.

TABLE 63.—*F. G. B., January 9, 1911. Chewing gum (3 grams). Lying.* (Values per minute.)

Time.	Average respiration rate.	Carbon dioxide.	Respiratory quotient.	Oxygen.	Average pulse rate.	Heat (computed).
		c.c.		*c.c.*		*cals.*
Without food:						
Av. of 2 periods.....	14	244	0.94	259	68	1.29
Chewing gum:[1]						
9^h22^m a.m.....	15	254	.88	288	73	1.41
9 50 a.m.....	15	270	.92	295	74	1.46

[1]Subject began chewing at 9^h08^m a. m.

TABLE 64.—*F. G. B., May 5, 1911. Chewing gum (6 grams). Lying.* (Values per minute.)

Time.	Average respiration rate.	Carbon dioxide.	Respiratory quotient.	Oxygen.	Average pulse rate.	Heat (computed).
		c.c.		*c.c.*		*cals.*
Without food:						
Av. of 2 periods.....	13	207	0.85	243	62	1.18
Chewing gum:[1]						
11^h03^m a.m.....	15	237	.86	274	64	1.34
11 30 a.m.....	11	259	.88	296	65	1.45

[1]Subject began chewing at 10^h52^m a. m.

TABLE 65.—*V. G., January 31, 1911. Chewing rubber stopper. Lying.* (Values per minute.)

Time.	Average respiration rate.	Carbon dioxide.	Respiratory quotient.	Oxygen.	Average pulse rate.	Heat (computed).
		c.c.		*c.c.*		*cals.*
Without food:						
Av. of 3 periods.....	19	190	0.84	227	59	1.10
Chewing:[1]						
11^h26^m a.m.....	19	213	....	...	68	1.22
11 51 a.m.....	19	218	....	...	69	1.25
12 16 p.m.....	18	222	....	...	69	1.27

[1]Subject began chewing stopper at 11^h20^m a. m.

TABLE 66.—*J. J. C., February 7, 1911. Chewing rubber stopper. Lying.* (Values per minute.)

Time.	Average respiration rate.	Carbon dioxide.	Respiratory quotient.	Oxygen.	Average pulse rate.	Heat (computed).
		c.c.		*c.c.*		*cals.*
Without food:						
Av. of 3 periods.....	17	183	0.80	229	65	1.10
Chewing:[1]						
1^h03^m p.m.....	20	222	.81	273	67	1.31
1 31 p.m.....	21	215	.77	278	71	1.32
1 54 p.m.....	19	208	....	...	70	1.26

[1]Subject began chewing stopper at 12^h50^m p. m.

TABLE 67.—*Increase in metabolism of subjects drinking water, coffee, and beef tea, and chewing gum.* (Calorimeter experiments; subject sitting.)[1]

Group and subject.	Date and place of experiments.	Amount of material.	Approximate temperature of material.	Duration of period.	Basal value for period.	Increment of heat.	
						Amt.	Per cent of basal value.
Chewing gum:	*Middletown.*	*grams.*	*°C.*	*hrs. min.*	*cals.*	*cals.*	
A. L. L.....	Apr. 3, 1906	15	..	4 0[2]	294	17	6
H. R. D.....	Apr. 4, 1906	15	..	4 0[2]	296	−3	−1
H. B. W.....	Apr. 26, 1907	30	..	3 51[2]	320	5	2
	Boston.						
J. J. C.....	Mar. 25, 1910	..	..	1 48[2]	142	−1	−1
V. G.....	Dec. 19, 1910[3]	..	..	2 24[2]	161[3]	26[3]	16
V. G.....	Jan. 2, 1911	6	..	1 30[2]	124	−1	−1
T. M. C.....	Jan. 3, 1911	..	..	1 23[2]	87	4	5
T. M. C.....	Jan. 7, 1911	..	..	1 23[2]	77	7	9
Water:[4]	*Middletown.*						
A. H. M.....	Mar. 16, 1907	1,584	22	8 0	656	24	4
A. W. W.....	Mar. 27, 1907	3,935	22—11	8 0	320	−19	−3
	Boston.						
J. J. C.....	Jan. 10, 1911	1,547	21	2 15	177	6	3
T. M. C.....	Jan. 12, 1911	1,800	22	2 15	138	22	16
J. J. C.....	Jan. 13, 1911	1,800	21	2 15	168	26	15
Coffee and sugar:	*Middletown.*						
A. W. W.....	Apr. 12, 1907	294[5]	72	8 0	620	−18	−3
A. H. M.....	Apr. 19, 1907	1,073[6]	56 to 66	8 0	656	73	11
Beef tea:[7]	*Middletown.*						
E. H. B.....	Apr. 8, 1907	892	82	8 0	716	−11	−2
A. H. M.....	Apr. 29, 1907	1,143	22	8 0	656	13	2
A. W. W.....	May 2, 1907	2,056	22 to 7	8 0	620	4	1
A. W. W.....	May 9, 1907	1,605	54	8 0	620	22	4
A. H. M.....	May 10, 1907	892	50	8 0	608[8]	20[8]	3
	Boston.						
J. J. C.....	May 12, 1910	1,222	15 to 38	4 0	316	−1	0
J. R.....	May 13, 1910	314	44.1	4 0	320	−8	−3

[1]Except in experiment with V. G., Dec. 19, 1910.
[2]Period here given is the actual time of chewing.
[3]Subject in bed calorimeter.
[4]Taken in varying amounts at intervals during experiments. For details, see tables 69 to 73.
[5]Subject finished drinking coffee 13 minutes after beginning of experiment.
[6]About 250 grams at beginning of each hour in first 4 hours of the experiment.
[7]Subject finished drinking beef tea from 14 to 38 minutes *after* the beginning of the respective experiments in the Middletown series; from 25 to 31 minutes *before* the experiments in the Boston series.
[8]Obtained by indirect calorimetry.

TABLE 68.—*Increase in metabolism of subjects drinking water, coffee, and beef tea, and chewing gum.* (Respiration experiments; subject lying.)

Group and subject.	Date.	Amount of material.	Temperature of material.	Duration of period.[1]	Basal value for period (computed).	Increment of heat (computed).	
						Amt.	Per cent of basal value.
Chewing gum:[2]	1910.	*grams.*	°*C.*	*hrs. min.*	*cals.*	*cals.*	
T. M. C.....	Dec. 17	6	....	1 0	55	7	13
	1911.						
J. J. C.....	Jan. 4	9	....	1 48	117	19	16
V. G.....	Jan. 5	([3])	....	2 19	157	42	27
F. G. B.....	Jan. 9	3	....	.. 57	74	8	11
F. G. B.....	May 5	6	....	.. 53	63	11	17
Chewing stopper:							
V. G.....	Jan. 31	...	....	1 11	78	11	14
J. J. C.....	Feb. 7	...	....	1 19	87	16	18
Water:							
V. G.....	Jan. 31	200	50.5	.. 56	62	−1	−2
J. J. C.....	Feb. 7	300	57.4	1 26	95	2	2
C. H. H.....	Mar. 24	325	58.0	1 59	124	−6	−5
J. P. C.....	Mar. 27	325	53.0	1 16	81	0	0
A. G. E.....	Mar. 28	325	55.0	2 43	168	3	2
F. G. B.....	May 5	500	11.0	.. 50	59	1	2
Coffee:							
J. J. C.....	Mar. 9	325	56.2 to 53.3	5 29	352	46	13
J. J. C.....	Mar. 21	325	([4])	3 28	233	22	9
L. E. E.....	Mar. 23	325	([4])	3 50	265	26	10
C. H. H.....	Mar. 24	325	60.0	1 31	95	2	2
H. L. H.....	Mar. 25	325	60.0	2 14	158	10	6
J. P. C.....	Mar. 27	312	52.0	2 22	152	13	9
Beef tea:							
J. J. C.....	Jan. 25	400	53.0 to 50.0	4 57	333	41	12
V. G.....	Jan. 26	400	55.2 to 53.6	6 25	420	33	8
C. H. H.....	Jan. 27	400	52.8 to 52.0	5 52	352	16	5
C. H. H.....	Feb. 2	400	61.4 to 59.0	6 5	361	21	6
V. G.....	Feb. 3	269	58.7 to 60.0	6 48	437	44	10
C. H. H.....	Feb. 8	350	55.4 to 50.0	4 55	298	17	6

[1]Period here given is the time between drinking of material or beginning of chewing to the end of the last period on the respiration apparatus.
[2]One piece of chewing gum has been found to weigh 3 grams.
[3]Amount of gum not recorded.
[4]Temperature not recorded.

DISCUSSION OF RESULTS OF CHEWING EXPERIMENTS.

In two of the Middletown calorimeter experiments, slight increments in the heat output were observed; the third showed a slight decrease. The data in tables 52 to 54 also show that the increments in the values for the gaseous metabolism approximated those found for the heat production. Thus the work of chewing gum performed by these subjects during a period of approximately 4 hours usually produced on the average a slight increase over the basal metabolism.

In the five experiments made with the chair and bed calorimeters in Boston, the time of actual chewing was considerably shorter than in the Middletown experiments, being approximately $1\frac{1}{4}$ to $2\frac{1}{2}$ hours in duration. In two of the experiments there was practically no variation in the metabolism; the other three experiments showed an increment of 5, 9, and 16 per cent, respectively. In one of these experiments, that with T. M. C. on January 7, 1911, the increment in the heat production was actually somewhat less than the increment noted in the gaseous metabolism, yet it points towards a true increase in the metabolism. In the bed-calorimeter experiment with V. G. on December 19, 1910, in which the high increment of 16 per cent was obtained, the increase in the heat output was somewhat higher than that shown for the carbon-dioxide production, which was but 8 per cent, and for the oxygen consumption, which was but 7 per cent. It is thus not impossible that errors in the measurement of the heat production may account for the abnormally high percentage increase in this factor. Disregarding the heat value obtained in this experiment with V. G. and substituting that obtained for the gaseous metabolism of about 8 per cent, the increment in the calorimeter experiments due to chewing gum will average approximately 3 per cent, with wide variations which include three negative values.

Measuring the metabolism with a respiration apparatus during the chewing of gum has certain technical difficulties which at first were thought to be insurmountable. By using nosepieces instead of a mouthpiece and giving careful instructions to the subjects, it was possible to make five experiments with four subjects. In all of the respiration experiments it was necessary to obtain the heat output by the indirect method of computing it from the gaseous metabolism. In considering the results of the chewing experiments, therefore, it is especially important to note any possibility of loss of carbon dioxide or intake of oxygen through the mouth during chewing, for naturally any leakage of air into or out of the mouth during the periods of observation would cause a disturbance in the measurements of the metabolism. If the results recorded show similar changes in the values for the carbon-dioxide production and oxygen consumption, it may be taken as an indication that there was little, if any, leakage of air

through the mouth. In a number of instances it was impossible to obtain an accurate measure of the oxygen consumed, owing to carelessness on the part of the subject in opening the mouth during chewing. This was especially true with the subjects V. G. and J. J. C. On the other hand, F. G. B. and T. M. C. took especial care to prevent such losses and the respiratory quotients found indicate that there was no disturbance and no appreciable leak. Hence we may properly assume that there was an actual increment in the metabolism which was measured with a considerable degree of accuracy.

The summary of the results of the respiration experiments given in table 68 shows in all cases measurable increases in the metabolism, these varying from 11 to 27 per cent. In the experiments in which the oxygen measurement was lost, due to the carelessness of the subject in opening the mouth while chewing, the carbon-dioxide measurements were used for computing the heat output. The calorific value of carbon dioxide used was the one corresponding to the respiratory quotients found prior to the chewing period, or in the few cases when quotients after the chewing period were available, an average of the two sets of quotients was used. It is of course possible that when the mouth was opened during chewing there was an increase in the carbon-dioxide excretion as a result of an excessive ventilation of the lungs. If this were the case it might account for the increase in the heat output attributed to the chewing, since in these cases the carbon-dioxide production was the only factor of metabolism available. In the experiments with F. G. B. and T. M. C. it is reasonably certain that there was no such loss through the mouth; the heat values could therefore be computed from the oxygen consumption.

The data secured in the respiration experiments show that as a result of chewing gum the basal metabolism may be increased on the average approximately 17 per cent. The diversity of results in the calorimeter experiments may be partly explained by the fact that the experiments were carried out over a considerable period of time, and the total increment formed a relatively small proportion of the total heat measured. The conclusion is warranted, however, that chewing gum results in a positive increase in the metabolism of from 10 to 17 per cent. Although an analysis of the chewing gum shows that from 62 to 69 per cent of carbohydrates was present, it is certain that this small amount of gum—*i. e.*, 3 to 30 grams—had no influence upon the metabolism.

Supplementary evidence in regard to the work of mastication was obtained in two experiments in which the subjects vigorously chewed a rubber stopper. Both experiments were made with the respiration apparatus, unfortunately with the less reliable subjects J. J. C. and V. G. The increase in the metabolism was essentially the same as that found with the other subjects in the gum-chewing experiments,

namely, 18 and 14 per cent, respectively, or 16 per cent on the average, thus verifying completely the more carefully planned experiments on chewing gum. It would appear from the data obtained in this study that the work of mastication, such as would be involved in chewing gum or a rubber stopper continuously, may temporarily require an increment in the metabolism of approximately 17 per cent.

In general agreement with the rise in metabolism due to chewing gum and a rubber stopper, the pulse rate is found to have increased in nearly all of the experiments. In the calorimeter experiments in Boston the pulse rate increased 9 to 10 beats per minute in all except those with J. J. C., March 25, 1910, and V. G., January 2, 1911. In the experiments with the respiration apparatus an increase was found in practically all of the experiments, the increase in the averages ranging from 3 beats per minute with F. G. B. on May 5, 1911, to 25 beats with V. G. on January 5, 1911.

At this point we are certainly justified in calling attention to the relation of the measured increase in the metabolism to the question of prolonged mastication. One of the arguments which has been advanced is that such mastication insures the absorption of a larger proportion of material from the ingested food. The fallacy of this reasoning is clearly shown when it is seen that digestion experiments have established the fact that with ordinary mastication from 90 to 95 per cent of the total energy of foodstuffs is completely absorbed.

The common method of making digestion experiments is to determine the protein, fat, and carbohydrates in the food eaten, and to calculate or determine its heat of combustion. The quantities of the same factors are determined in the feces and the ratios of the differences between these two series of values to those of the food itself are reported as the coefficients of digestibility. This method of determining the digestibility is based upon the archaic conception that feces consist primarily of the undigested residue of food. As is now known, undigested food forms but a small part of the feces and the ratio is in fact much higher than the commonly stated proportion of 90 to 95 per cent. Even on the basis of the older interpretation, however, the possibility of increasing the digestibility or availability of foodstuffs by extreme mastication seems very small. Furthermore, when we find that this prolonged mastication demands an excess heat production of approximately 17 per cent above the basal value it is easily seen that any advantage gained from a possible increase in the digestibility of the food is more than compensated by the increase in the heat production. The conception of an increase in the digestibility and in the utilization of the energy of foodstuffs as a result of prolonged mastication thus finds no support in fact.

INGESTION OF WATER.

Large amounts of water are regularly consumed by all individuals throughout life. Since one or more liters pass through the body in 24 hours, it is hardly conceivable that such passage is unaccompanied by energy transformations; the processes of absorption and secretion should also be taken into consideration. Furthermore, the taking of water at various temperatures frequently produces distinct subjective effects and (at times) effects of a physiological nature, such as an inclination to defecation. A study of the question as to whether or not the drinking of water produces a measurable effect on the basal metabolism is therefore of prime importance.

The literature is very deficient in definite information regarding the influence of water-drinking upon the metabolism. The most detailed experiments are those carried out in Rubner's laboratory by Laschtschenko,[1] who concludes that the drinking of water at room temperature (approximately 18° C.) has no influence upon the carbon-dioxide production. Water at 32° to 33° C. produced a very slight increase, but at 37° C. there was practically no increase in the carbon-dioxide production.

Although the effect of water-drinking on the metabolism was studied by Berg,[2] the technique was too unreliable to permit deductions from the experiments. Speck,[3] who worked with a much more satisfactory technique in the experiments upon himself, concludes that drinking large amounts of water before an experiment has no influence upon the oxygen consumption or carbon-dioxide production. He found, however, that when 1,250 c.c. of water were taken inside of one hour and observations were begun 30 minutes after the water had been taken, there was a noticeable rise in the metabolism; in this experiment the author noted shivering. He considered that the rise was due to a stimulus of the digestive canal, of which he became aware shortly after taking the water because of the movement of gas in the intestines.

Loewy[4] reports that immediately after the ingestion of 100 grams of cold water there was pressure and discomfort in the intestines, which was followed a half hour afterward by a movement of the bowels. The water caused an increase of but 2 per cent in the oxygen consumption with a great increase in the carbon-dioxide production. In his second experiment, in which the same amount of water was given, there was an increase of 1.5 per cent in the oxygen consumption 11 minutes after the water was taken and an increase of approximately 6 per cent 33 minutes after the drinking of the water. Thus Loewy found no definite increment in the metabolism as a result of the ingestion of pure water. Since, however, his technique as a whole has been

[1] Laschtschenko, Arch. f. Hygiene, 1898, **33**, p. 145.
[2] Berg, Deutsch. Arch. f. klin. Med., 1869, **6**, p. 291.
[3] Speck, Physiologie des menschlichen Athmens, 1892, p. 42.
[4] Loewy, Arch. f. d. ges. Physiol., 1888, **43**, p. 525.

criticized[1] and a duplication of the experiments has not resulted in confirming his original observations, it is not possible to place much emphasis upon his findings.

Probably no factor makes direct calorimetry so difficult in a study of the effect of food on the metabolism as does the ingestion of liquids, which are almost invariably taken into the body at temperatures considerably below or above the body-temperature. Water is usually taken at a temperature below that of the body, while coffee, tea, and thin extracts or soups are ordinarily taken at a temperature above. The question of the temperature adjustment inside the body is therefore somewhat important. While the rectal temperature gives a remarkably good indication of the average body-temperature, it is by no means certain that the large amounts of heat required to warm a considerable quantity of water from 10° C. to body-temperature may not seriously disturb the temperature distribution. Indeed, in certain experiments reported from this laboratory,[2] the ingestion of water produced a noticeable change in rectal temperature. The experience of Rancken, in Tigerstedt's laboratory in Helsingfors,[3] shows that the rectal temperature, although instantly affected by the ingestion of cold liquids, returns to its original value in about 30 minutes, indicating that the equalization of temperature is rapid. In a recent series of observations Stengel and Hopkins,[4] employing a thermo-couple, found that after the ingestion of 120 c.c. of ice water the temperature of the stomach dropped rapidly 1° to 14° C. and returned to normal in from 19 to 31 minutes.

The experimental difficulties experienced by Lusk[5] when giving a dog large amounts of water and meat just taken from an ice chest illustrate very clearly the disturbance in the heat distribution and incidentally the difficulties of determining the heat production by direct calorimetry when a large amount of material is ingested at a temperature considerably above or below that of the body.

STATISTICS OF EXPERIMENTS.

The effect of water-drinking was studied in this research in five calorimeter experiments and six respiration experiments. The experiments with the respiration calorimeter at Middletown, Connecticut, consisted of two 8-hour observations in which large amounts of water, 1,584 grams and 3,935 grams, respectively, were taken by the two subjects. (See tables 69 and 70.) With the chair calorimeter in Boston three experiments were made in January 1911, in which approximately 1,800 grams were taken by each subject. (See tables 71 to 73.) In the shorter observations with the respiration apparatus six subjects were

[1]Benedict and Emmes, Am. Journ. Physiol., 1912, **30,** p. 197.
[2]Benedict and Slack, Carnegie Inst. Wash. Pub. No. 155, 1911, p. 73.
[3]Rancken, Skand. Arch. f. Physiol., 1908, **21,** p. 161.
[4]Stengel and Hopkins, Am. Journ. Med. Sci., 1917, **153,** p. 101.
[5]Lusk, Journ. Biol. Chem., 1915, **20,** p. 555; see especially pp. 558, 576, and 615.

studied who were given from 200 to 500 grams of water, the temperature of the water in all but one case being somewhat over 50° C. (See tables 74 to 79.) The increments in the heat production are summarized in tables 67 and 68. (See pages 135 and 136.)

The method used for computing the increment in the water experiments with the respiration apparatus was that employed in the experiments with chewing. (See page 127.) The basal value for the day was obtained in a series of 15-minute observations when the subject was without food or water. The second series began 5 to 34 minutes after the subject had taken water; the intervals between the periods were from 14 to 29 minutes. The average heat production for the basal periods and the heat output for each of the periods with water are given in tables 74 to 79. The increment in the metabolism was obtained by comparing the average value for the basal periods with the heat production for each period after the ingestion of water. It is seen by an inspection of the tabulated data for this group of experiments that these small and in some cases negative increments in the heat production represent the results of two to four periods of measurement. The sum total of time for these measurements, which are obviously not continuous, is 30 to 60 minutes, extending over periods of 50 minutes to 2 hours and 43 minutes following the drinking of water. In calculating the total increments it was assumed that the rate of increase for the time between the drinking of the water and the end of the last period was the same as that observed in the measured periods.

For example, in the experiment with J. J. C., February 7, 1911 (see page 146), the basal value for the heat production is 1.10 calories per minute and the values for the respective periods after the water was taken are 1.10, 1.14, and 1.11 calories per minute. It is thus seen that the average increase per period and per minute is equivalent to 0.02 calorie. The time between the drinking of the water and the end of the last period (11^h05^m a. m. to 12^h31^m p. m.) was 86 minutes. The total increment computed as heat (86×0.02) was thus 2 calories. The basal value for a corresponding length of time (86×1.10) was 95 calories; the percentage increase in metabolism ($2 \div 95$) was, therefore, 2 per cent.

Statistical data not included in the tables or in the discussion are given in the following paragraphs for all of the experiments. The times given include both basal and water-drinking periods, when the basal values were determined immediately before the water-drinking.

CALORIMETER EXPERIMENTS.

A. H. M., 9^h28^m a. m. to 5^h28^m p. m., March 16, 1907. 66.3 kilograms.—Urinated shortly before 7 o'clock (after enema); attempted to urinate near beginning of each period, urinating at 9^h35^m a. m., 12^h46^m, 2^h32^m, 3^h34^m, and 5^h28^m p. m.; unable to urinate at end of either first or second period; some pressure from urine; some sensation of fullness from water-drinking. Drank water in each period. Stooped over in third period to pick up rubber stop-

per from floor; reported restless in last hour of fourth period; otherwise sitting quietly in chair, reading much of time. Body-temperature: 37.34°, 37.30°, 37.26°, 37.41°, and 37.44° C. Pulse rate, 50; respiration rate, 18.

A. W. W., 8h24m a. m. to 4h24m p. m., March 27, 1907. 58 kilograms.—Drank water twice in first period, four times in second, once in third, and four times in fourth period. Urinated about 7h15m a. m. (after enema), three times in second, once in third, and twice in fourth period. Activity other than indicated was small; part of time reading. Body-temperature: 36.71°, 36.48°, 36.71°, 36.73°, and 36.73° C. Pulse rate, 57; respiration rate, 23.

J. J. C., 9h08m a. m. to 1h39m p. m., January 10, 1911. 63.4 kilograms.—In three basal periods went through motions of drinking water and urinating to equalize muscular activity throughout experiment; an effort was also made to minimize activity by having urine jars and drinking-water on table conveniently placed and by use of bent-glass tube in drinking. Urinated at 7h55m and 11h30m a. m., 12h03m, 12h55m, 1h20m, and 1h49m p. m. Drank water three times in each of the water-drinking periods. Asleep at 10h52m a. m.; also slept in first water-drinking period. On evening of experimental day had slight tendency to diarrhea, probably due to excessive water drinking. Basal periods: pulse rate, 68; respiration rate, 17. Water-drinking periods: pulse rate, 70; respiration rate, 19.

T. M. C., 8h55m a. m. to 12h40m p. m., January 12, 1911. 47.5 kilograms.—Slightly more active in water-drinking periods than in two basal periods. Urinated at 7h15m, 10h28m, 11h58m a. m., 12h29m, and 12h48m p. m. In each water-drinking period subject drank water three times. Basal periods: pulse rate, 69; respiration rate, 15. Water-drinking periods: pulse rate, 70; respiration rate, 15.

J. J. C., 8h56m a. m. to 12h41m p. m., January 13, 1911. 64.9 kilograms.—At 11h30m p. m. on preceding day subject ate 5 tablespoonfuls chicken salad, 1 Vienna roll, 3 cupfuls coffee, 5 macaroons, 8 or 9 lady-fingers, one large dish sherbet and ice cream, one slice walnut cake. Activity due to water-drinking and urinating in last three periods simulated in two basal periods preceding. Water taken three times in each water-drinking period. Urinated at 7h50m, 10h33m, 11h14m, 11h59m a. m., 12h18m, and 12h47m p. m. In first basal period sat quietly reading; in second basal period slept about 8 minutes shortly after period began and fell asleep again near end of period. As pulse rate was indistinct in first water-drinking period, he readjusted stethoscope. Basal periods: pulse rate, 61; respiration rate, 18. Water-drinking periods: pulse rate, 58; respiration rate, 19.

TABLE 69.—*A. H. M., March 16, 1907. Sitting.* (2-hour periods.)

Water (22° C.), 1,584 grams.

Basal values (March 6 and 9, 1907): CO_2, 51 grams; O_2, 46 grams; heat, 164 cals. Nitrogen in urine, 0.96 gram per 2 hours (March 16, 1907).

Water consumed.[1]	Nitrogen in urine per 2 hours.	Carbon dioxide.		Oxygen.		Heat.	
		Total.	Increase.	Total.	Increase.	Total.	Increase.
grams.	*grams.*	*grams.*	*grams.*	*grams.*	*grams.*	*cals.*	*cals.*
434	1.23	51	0	45	−1	177	13
439	1.28	52	1	44	−2	160	−4
443	1.25	53	2	47	1	175	11
268	1.32	53	2	49	3	168	4
Total	....	209	5	185	1	680	24

[1]Subject drank the respective amounts at the beginning of the 2-hour periods.

TABLE 70.—*A. W. W., March 27, 1907. Sitting.* (2-hour periods.)

Water (22° C.), about 400 grams at 11° C. in last period), 3,935 grams.
Basal values (March 15 and 21, 1907): CO_2, 50 grams; O_2, 41 grams; heat, 155 cals.

Water consumed.[1]	Nitrogen in urine per 2 hours.	Carbon dioxide.		Oxygen.		Heat.	
		Total.	Increase.	Total.	Increase.	Total.	Increase.
grams.	*grams.*	*grams.*	*grams.*	*grams.*	*grams.*	*cals.*	*cals.*
1,313	0.42[2]	48	−2	34	−7	149	−6
1,021	1.06	53	3	44	3	152	−3
284	.51	47	−3	37	−4	135	−20
1,317	.80	54	4	47	6	165	10
Total	....	202	2	162	−2	601	−19

[1]Began drinking water with beginning of experiment.
[2]Sample includes amount for about an hour preceding experiment.

TABLE 71.—*J. J. C., January 10, 1911. Sitting.* (45-minute periods.)

Water (21° C.), 1,547 grams.
Basal values (January 10, 1911): CO_2, 19.5 grams; O_2, 17 grams; heat,[1] 59 cals.; respiratory quotient, 0.84. Nitrogen in urine, 0.44 gram per 45 minutes.

Water consumed.[2]	Nitrogen in urine per 45 minutes.	Carbon dioxide.		Oxygen.		Heat.[1]		Respiratory quotient.
		Total.	Increase.	Total.	Increase.	Total.	Increase.	
grams.	*gram.*	*grams.*	*grams.*	*grams.*	*grams.*	*cals.*	*cals.*	
674	0.42	21.5	2.0	26.5	3.5	68	9	0.77
375	.54	20.5	1.0	18.0	1.0	56	−3	.82
498	.49	21.0	1.5	19.5	2.5	59	0	.79
Total	....	63.0	4.5	58.0	7.0	183	6	....

[1]Heat eliminated corrected for change in body-weight, but not for change in body-temperature.
[2]Subject drank about 175 grams of water at each interval of about 10 to 20 minutes.

TABLE 72.—*T. M. C., January 12, 1911. Sitting.* (45-minute periods.)

Water (22° C.), 1,800 grams.
Basal values (January 12, 1911): CO_2, 14.5 grams; O_2, 13 grams; heat,[1] 46 cals.; respiratory quotient, 0.82. Nitrogen in urine, 0.21 gram per 45 minutes.

Water consumed.[2]	Nitrogen in urine per 45 minutes.	Carbon dioxide.		Oxygen.		Heat.[1]		Respiratory quotient.
		Total.	Increase.	Total.	Increase.	Total.	Increase.	
grams.	*gram.*	*grams.*	*grams.*	*grams.*	*grams.*	*cals.*	*cals.*	
600	0.36	15.0	0.5	16.0	3.0	57	11	0.68
600	.36	16.5	2.0	14.5	1.5	51	5	.85
600	.41	17.0	2.5	17.0	4.0	52	6	.72
Total	....	48.5	5.0	47.5	8.5	160	22	....

[1]Heat eliminated corrected for change in body-weight, but not for change in body-temperature.
[2]Subject drank 200 grams of water at each interval of about 15 minutes.

TABLE 73.—*J. J. C., January 13, 1911. Sitting.* (45-minute periods.)

Water (21°C.), 1,800 grams.

Basal values: CO_2, 20 grams (January 13, 1911); O_2, 17.5 grams (January 10–17, 1911); heat, 56 cals. (January 13, 1911); respiratory quotient, 0.85 (January 13, 1911). Nitrogen in urine, 0.38 gram per 45 minutes (January 13, 1911).

Water consumed.[2]	Nitrogen in urine per 45 minutes.	Carbon dioxide.		Oxygen.		Heat.[1]		Respiratory quotient.
		Total.	Increase.	Total.	Increase.	Total.	Increase.	
grams.	*gram.*	*grams.*	*grams.*	*grams.*	*grams.*	*cals.*	*cals.*	
600	0.45	20.5	0.5	20.0	2.5	67	11	0.75
600	.57	23.0	3.0	21.0	3.5	64	8	.80
600	.53	21.5	1.5	18.5	1.0	63	7	.84
Total..	....	65.0	5.0	59.5	7.0	194	26	....

[1]Heat eliminated corrected for change in body-weight, but not for change in body-temperature.
[2]Subject drank 200 grams of water at each interval of about 10 to 20 minutes.

RESPIRATION EXPERIMENTS.

V. G., 8h41m a. m. to 11h02m a. m., January 31, 1911. 54.9 kilograms.—Previous day, low carbohydrate diet. Between supper on preceding day and 8 a. m. of experimental day, walked 1.6 miles according to pedometer. Urinated 7h45m a. m. Slept a little in first basal period, still longer in second period, very sleepy in first part of third period, but wide awake in latter part, as special efforts were made to keep him awake. Very quiet in last water-drinking period; asleep part of the time. Blood pressure: basal periods, 102, 107, 105 mm.; after water, 103, 100 mm. Nitrogen in urine per hour 7h45m a. m. to 12h50m p. m., 0.32 gram.

J. J. C., 9h10m a. m. to 12h31m p. m., February 7, 1911. 63.9 kilograms.—Between 5 p. m., February 6, and 8 a. m., February 7, walked 1.5 miles according to pedometer. Very quiet throughout experiment; slept part of second basal period, and a little in first two periods after water. Urinated 7h30m a. m. and 2h16m p. m. Blood pressure: basal periods, 108, 111, 120 mm.; after water, 102, 105, 102 mm. Nitrogen in urine per hour 7h30m a. m. to 2h16m p. m., 0.41 gram.

C. H. H., 9h16m a. m. to 1h39m p. m., March 24, 1911. 54.9 kilograms.—Urinated at 8h15m a. m.; quiet throughout experiment. Pulse rate increased immediately after taking hot water, range between 11h45m a. m. and 12h15m p. m. being 63 to 79. Blood pressure: basal periods, 119, 122, 120, 120 mm.; after water, 119, 115, 104 mm. Nitrogen in urine per hour 8h15m a. m. to 4 p. m., 0.27 gram.

J. P. C., 9h04m a. m. to 11h22m a. m., March 27, 1911. 73.1 kilograms.—Mouthpiece and noseclips used instead of nosepieces; high carbohydrate diet on day preceding experiment. Urinated at 7 a. m., 11h53m a. m., and 2h15m p. m. Nitrogen in urine per hour 7 a. m. to 11h53m a. m., 0.42 gram.

A. G. E., 8h52m a. m. to 12h38m p. m., March 28, 1911. 56.9 kilograms.—Low carbohydrate diet day before. Awake and quiet during whole experiment; urinated at 7h30m a. m. and large amount at 2 p. m. Blood pressure: basal periods, 117, 116 mm.; after water, 126, 128, 119, 117 mm. Nitrogen in urine per hour 7h30m a. m. to 2 p. m., 0.48 gram.

F. G. B., 9h02m a. m. to 10h48m a. m., May 5, 1911. During first period after water had strong desire to urinate; urinated at 10h21m a. m., 10h54m a. m., and 11h47m a. m. Nitrogen in urine per hour 8h45m a. m. to 10h21m a. m., 0.57 gram; 10h21m a. m. to 10h54m a. m., 0.49 gram.

TABLE 74.—*V. G., January 31, 1911. Lying.* (Values per minute.)
Water (50.5° C.), 200 c.c.

Time.	Average respiration rate.	Carbon dioxide.	Respiratory quotient.	Oxygen.	Average pulse rate.	Heat (computed).
Without food:		*c.c.*		*c.c.*		*cals.*
Av. of 3 periods...	19	190	0.84	227	59	1.10
Water:[1]						
10^h14^ma.m.....	19	197	.88	224	66	1.10
10 47 a.m.....	18	191	.86	222	60	1.08

[1]Taken at 10^h06^m a. m.

TABLE 75.—*J. J. C., February 7, 1911. Lying.* (Values per minute.)
Water (57.4° C.), 300 c.c.

Time.	Average respiration rate.	Carbon dioxide.	Respiratory quotient.	Oxygen.	Average pulse rate.	Heat (computed).
Without food:		*c.c.*		*c.c.*		*cals.*
Av. of 3 periods...	17	183	0.80	229	65	1.10
Water:[1]						
11^h15^ma.m.....	19	197	.88	225	66	1.10
11 46 a.m.....	17	192	.81	237	64	1.14
12 16 p.m.....	17	190	.83	229	64	1.11

[1]Taken at 11^h05^m a. m.

TABLE 76.—*C. H. H., March 24, 1911. Lying.* (Values per minute.)
Water (58° C.), 325 c.c.

Time.	Average respiration rate.	Carbon dioxide.	Respiratory quotient.	Oxygen.	Average pulse rate.	Heat (computed).
Without food:		*c.c.*		*c.c.*		*cals.*
Av. of 4 periods...	14	178	0.83	214	62	1.04
Water:[1]						
12^h14^mp.m.....	13	180	.88	203	64	0.99
12 56 p.m.....	12	173	.85	204	63	.99
1 24 p.m.....	14	173	.84	207	63	1.00

[1]Taken at 11^h40^m a. m.

TABLE 77.—*J. P. C., March 27, 1911. Lying.* (Values per minute.)
Water (53° C.), 325 c.c.

Time.	Average respiration rate.	Carbon dioxide.	Respiratory quotient.	Oxygen.	Average pulse rate.	Heat (computed)
Without food:		*c.c.*		*c.c.*		*cals.*
Av. of 2 periods...	18	188	0.86	219	52	1.07
Water:[1]						
10^h37^ma.m.....	18	186	.84	221	52	1.07
11 07 a.m.....	19	189	.86	220	51	1.07

[1]Taken at 10^h06^m a.m.

TABLE 78.—*A. G. E., March 28, 1911. Lying.* (Values per minute.)
Water (about 55° C.), 325 c.c.

Time.	Average respiration rate.	Carbon dioxide.	Respiratory quotient	Oxygen.	Average pulse rate.	Heat (computed).
		c.c.		*c.c.*		*cals.*
Without food:						
Av. of 2 periods...	11	178	0.84	213	63	1.03
Water:[1]						
10h26ma.m.....	11	176	.86	205	64	1.00
10 58 a.m.....	11	175	.80	218	66	1.05
11 42 a.m.....	11	183	.79	231	64	1.11
12 23 p.m.....	13	177	.82	217	64	1.05

[1]Taken at 9h55m a. m.

TABLE 79.—*F. G. B., May 5, 1911. Lying.* (Values per minute.)
Water (11° C.), 500 c.c.

Time.	Average respiration rate.	Carbon dioxide.	Respiratory quotient.	Oxygen.	Average pulse rate.	Heat (computed).
		c.c.		*c.c.*		*cals.*
Without food:						
Av. of 2 periods...	13	207	0.85	243	62	1.18
Water:[1]						
10h03ma.m.....	13	198	.80	247	64	1.19
10 33 a.m.....	14	209	.85	245	60	1.19

[1]Taken between 9h54m and 9h58m a. m.

DISCUSSION OF RESULTS OF WATER-DRINKING EXPERIMENTS.

Of special significance is the fact that in the three Boston calorimeter experiments the heat output as reported is heat eliminated and not heat produced; that is, the heat measurements have not been corrected for changes in the body-temperature. From an inspection of the data giving the increments in the water-drinking periods, it will be seen that in most cases the gaseous metabolism shows a positive increase corresponding to the increase in the heat output and in some instances it is roughly proportional to the increase in the heat. This, to a certain degree, confirms the validity of the heat measurements, even when not corrected for changes in the body-temperature.

In the final summaries, given in tables 67 and 68 (see pages 135 and 136), the total increments and the percentage increments are based solely upon the heat measurements. The values in table 67 show that in all but one of the calorimeter experiments, that with A. W. W. on March 27, 1907, there was a positive increase in the heat output as a result of taking water. In only two of the calorimeter experiments, those of January 13, 1911, with J. J. C., and January 12, 1911, with T. M. C., can the increments be considered as really significant,

these being 15 and 16 per cent, respectively. While the results of the experiment on January 13 may be open to the general criticism that J. J. C. was, as a rule, an unsatisfactory subject in many ways, yet so far as we can see there is nothing about the experiment which can be criticized, and we believe that the increment of 15 per cent represents a true increment. Reference to table 73 shows that in the experiment with J. J. C. on January 13, the total increase in the carbon-dioxide production was 8 per cent and in the oxygen consumption it was 13 per cent of the basal value. In the experiment with T. M. C. on January 12 (see table 72), the total increase in the carbon-dioxide production was 11 per cent and in the oxygen consumption 22 per cent. Evidently in both these cases there were actual increments in the metabolism due to the drinking of water.

The two experiments with the high increments were made with the chair calorimeter in Boston and in periods approximately $2\frac{1}{4}$ hours in length. The series of experiments with the universal respiration apparatus, in which the periods were approximately 15 minutes each but which covered a total period between the drinking of the water and the end of the last period of 50 minutes to approximately $2\frac{3}{4}$ hours, shows values considerably at variance with those obtained with the calorimeter. (See table 68.) In no case was the increment over 2 per cent and in two out of the six experiments there was, as a matter of fact, a slight decrease. The amount of water taken in these respiration experiments was much smaller than that taken in the calorimeter experiments, but this can not account entirely for the small increments, as the calorimeter experiment with A. W. W. on March 27, 1907, in which the largest amount of water was taken, namely, 3,935 grams, resulted in a decrease in the metabolism of 3 per cent.[1]

From the results of both series of experiments it is safe to conclude that when not over 500 grams of water are taken, as in the respiration experiments, the ingestion of water with a temperature of either 22° or 55° C. produces no significant increment of the basal metabolism. Since the two calorimeter experiments on January 12 and 13, 1911, apparently showed true increments in the metabolism due to water-drinking, there may be with more than 500 grams of cold water an increase as great as 16 per cent above the basal value. Although the subjective impressions of the two men showing the large increment were not recorded with sufficient detail to indicate any peculiar sensations, it is not impossible that we may have here a nervous phenomenon not unlike those mentioned by Loewy. (See page 140.)

The pulse was counted in a considerable number of instances; measurements were likewise made of the blood pressure by means of

[1]Mention should here be made of the experiments carried out by Ranke (see table 2, p. 17) in which the carbon-dioxide production for 24 hours of fasting without water was 663.5 grams, and on another day with the subject fasting with 2,109 c.c. water it was 662.9 grams.

the Erlanger sphygmomanometer. A general inspection of these results shows nothing significant in the changes in either pulse or blood pressure as a result of the ingestion of water.

In experiments of this kind one might maintain that it would be more logical to attempt a correlation of the metabolism with the total quantity of urine passed rather than with the amount of water taken, since it is conceivable that the mechanical work of the processes involved would be shown more clearly by the volume of urine excreted. As would be expected, the volume of urine increased considerably when large quantities of water were consumed, but the amounts of urine excreted were usually not abnormal, and we were unable to discover any definite correlation between the volume of urine and the total metabolism.

INGESTION OF COFFEE.

Although the earlier experimenters made but few observations on the effect of drinking hot or cold water, we find a number of studies on the effect of taking tea and coffee. Of special interest is the series of experiments made by Böcker,[1] who concludes that the taking of coffee decreases both extensively and intensively the respiratory processes. Edward Smith[2] has a series of observations on drinking both tea and coffee, and concludes that tea is a powerful respiratory stimulus, coffee being but little less powerful. With the technique used by both these investigators, it was not possible to study the fine differences which in later times have been found to exist; hence their results can not be considered as conclusive.

Speck[3] studied the effect of coffee-drinking in two experiments and found a small but visible rise in the carbon-dioxide production and oxygen consumption, indicating to his mind a distinct stimulus to the digestive activities. Lehmann and Rohrer[4] found that the volatile constituents of tea and coffee did not cause any noticeable changes in the respiration frequency. A series of papers from the Russell Sage Institute of Pathology has just appeared which includes a paper by Means, Aub, and Du Bois,[5] reporting the results of a study in which four normal subjects were given from 8 to 10 grains of caffein—*i. e.*, 8.6 milligrams per kilogram of body-weight. The authors state that the basal metabolism was increased from 7.4 to 23.5 per cent, these values representing average "peak" effects. Of special significance is the fact that there was no material change in the pulse rate.

STATISTICS OF EXPERIMENTS.

Our own observations with coffee include two calorimeter experiments made in Middletown and six respiration experiments in Boston. The results are given in tables 80 to 87 and discussed in the accompanying text. They are also summarized in tables 67 and 68. (See pages 135 and 136.)

In all of the experiments the coffee was taken hot; in the two calorimeter experiments a certain amount of sugar was also taken. The general plan of both series of experiments was similar to that of the water-drinking studies. The measurement of the gaseous metabolism in the respiration experiments began 6 to 32 minutes after the drinking of the coffee; the total time between the taking of coffee and the end of the last period ranged from 1 hour 31 minutes to 5 hours 29 minutes.

The method of determining the total increment in the respiration experiments was unlike that used in the chewing and water-drinking studies in that the increase was found here by measuring plotted areas

[1] Böcker, Beiträge zur Heilkunde, 1849, **1**, p. 200.
[2] Smith, Phil. Trans., 1859, **149**, p. 715.
[3] Speck, Physiologie des menschlichen Athmens, 1892, p. 42.
[4] Lehmann and Rohrer, Arch. f. Hyg., 1902, **44**, p. 263.
[5] Means, Aub, and Du Bois, Arch. Intern. Med., 1917, **19**, p. 832.

superimposed upon the base-lines determined on the respective days. The average heat production (computed) per minute, plotted for the average time of the periods, supplied the points for defining the area of increment. Inasmuch as this method was followed for all of the respiration experiments except the water-drinking and chewing studies, it is described in detail here and two illustrative curves are given (figures 1 and 2).

The curve in figure 1 is that for the coffee experiment with L. E. E., March 23, 1911. (See table 84.) The basal value for this day was 1.15 calories; the time between the drinking of 325 grams of coffee and the end of the last period was 3 hours 50 minutes. The initial value for this curve is on the base-line at the point indicated on the horizontal scale as 0, this being the time when the subject finished drinking the coffee—*i. e.*, at 10^h10^m a. m. The point plotted 29 minutes later is for 1.28 calories at the average time of the first period, that is, at 10^h39^m a. m. Values have been similarly plotted at six other points—*i. e.*, 1.21 calories at 58 minutes, 1.28 calories at 1 hour 26 minutes, 1.29 calories at 1 hour 58 minutes, 1.28 calories at 2 hours 29 minutes, 1.26 calories at 3 hours 4 minutes, and 1.28 calories at 3 hours 43 minutes after taking the coffee. The curve has been extended to reach a perpendicular dropped to the base-line at the point of time corresponding to the end of the last period of the experiment. The area thus inclosed by the curve and base-line is considered to represent the total increment for the period of observation following the drinking of the coffee. With a planimeter this area measured 4.25 units, and since each unit of area represents a value of 6 calories, the total increment (6×4.25) was therefore 26 calories. The basal value corresponding to the period of 3 hours 50 minutes or 230 minutes (230×1.15) would be 265 calories. The percentage increase in the metabolism ($26 \div 265$) was therefore 10 per cent.[1]

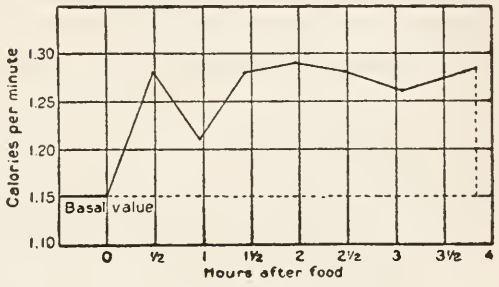

FIG. 1.—Curve showing increment of heat production following ingestion of 325 c.c. of coffee in experiment with L. E. E., March 23, 1911.

The planimeter method used in the coffee and beef-tea experiments for determining the increment in the heat output was also used in the respiration experiments with other food materials for computing the percentage obtained by a comparison of the increment in the heat output with the fuel value of the food material ingested—*i. e.*, the "cost of digestion."[2] To illustrate this method as employed in experiments

[1]See table 68, p. 136. [2]See discussion of these values, p. 335 *et seq.*

with food materials having a high energy value and consequently a great effect on the metabolism, the curve for the beefsteak experiment with Dr. S. on June 30, 1911,[1] is given in figure 2. In this experiment 177 grams of beefsteak were taken by the subject. The last experimental period was completed 6 hours 35 minutes after he had finished eating. The points in the curve were plotted and area of increment defined as for the curve in figure 1. The total area, as measured by the planimeter, was 9.32 units, corresponding to 56 calories. The fuel value of the beefsteak ingested was 298 calories; the increment (56 ÷ 298) was therefore 19 per cent of the fuel value. (See table 215, page 284.)

Statistical data not included in the tables or in the discussion are given in the following paragraphs for all of the experiments. Whenever the basal values were determined immediately before the coffee-drinking, the times given include both basal and coffee periods.

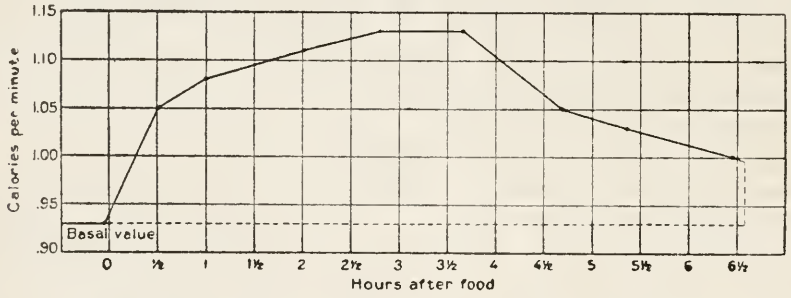

FIG. 2.—Curve showing increment of heat production following ingestion of 177 grams of beefsteak in experiment with Dr. S., June 30, 1911.

CALORIMETER EXPERIMENTS.

A. W. W., 8h21m a. m. to 4h21m p. m., April 12, 1907. 58.6 kilograms.—No apparent diuretic or bad effects from drinking coffee. Urinated at 7h10m a. m. (after enema) and once in every period except first; drank water at beginning of both third and fourth periods (303.5 grams in all). Less quiet in fourth period than in others. Body-temperature, 36.58°, 36.89°, 36.93°, 37.03°, and 37.05° C. Pulse rate, 62; respiration rate, 21.

A. H. M., 8h09m a. m. to 4h09m p. m., April 19, 1907. 66 kilograms.—Coffee made in a percolator in proportion of one tablespoonful coffee to one cupful water; strong infusion obtained after boiling for some time. Subject directed to drink during the experiment a cupful of coffee each hour until he could take no more; was not a coffee drinker. Cupful of coffee with two teaspoonfuls of sugar taken at 8h18m, 9h18m, 10h20m, and 11h18m a. m., and 5.2 grams coffee, with no sugar, at 12h24m p. m. Telephoned twice in each period but last; opened food aperture, without rising from chair, twice in both first and second periods and once in third period; urinated about 4h30m a. m. and once in each period of experiment except first; activity slight otherwise; reading most of time. Said first two cupfuls tasted very good, next two cupfuls taken with difficulty, and could take but little afterwards. Slight dizziness after 12 o'clock; urinated more freely than usual but drank no water. Body-temperature: 36.86°, 36.76°, 36.92°, 36.71°, 36.76° C. Pulse rate, 63; respiration rate, 18.

[1]See table 215, p. 284.

TABLE 80.—*A. W. W., April 12, 1907. Sitting.* (2-hour periods.)

Coffee (72° C.) and sugar:
Amounts, 271 grams coffee, 23 grams sugar; nitrogen, 0.08 gram; total energy, 105 cals.
Fuel value: Total, 105 cals.; from protein, 2 p. ct.; from carbohydrates, 98 p. ct.
Basal values (March 15 and 21, 1907): CO_2, 50 grams; O_2, 41 grams; heat, 155 cals.

Time elapsed since subject finished eating.	Nitrogen in urine per 2 hours.	Carbon dioxide.		Oxygen.		Heat.	
		Total.	Increase.	Total.	Increase.	Total.	Increase.
	gram.	*grams.*	*grams.*	*grams.*	*grams.*	*cals.*	*cals.*
0 to 2 hours[1]..	0.95[2]	54	4	48	7	167	12
2 to 4 hours..	.95[2]	50	0	34	−7	142	−13
4 to 6 hours..	.73	48	−2	43	2	140	−15
6 to 8 hours..	.71	48	−2	41	0	153	− 2
Total...	....	200	0	166	2	602	−18

[1]Subject finished drinking coffee 13 minutes after the beginning of this period. The drinking was done quickly.
[2]Sample included amount for about 1¼ hours, without food, preceding experiment.

TABLE 81.—*A. H. M., April 19, 1907. Sitting.* (2-hour periods.)

Coffee (56 to 66.5° C.) and sugar:
Amounts, 1,011 grams coffee, 62 grams sugar; nitrogen, 0.39 gram; total energy, 300 cals.
Fuel value: Total, 296 cals.; from protein, 3 p. ct.; from carbohydrates, 97 p. ct.
Basal values (March 6 and 9, 1907): CO_2, 51 grams; O_2, 46 grams; heat, 164 cals.

Coffee.[1]	Nitrogen in urine per 2 hours.	Carbon dioxide.		Oxygen.		Heat.	
		Total.	Increase.	Total.	Increase.	Total.	Increase.
grams.	*grams.*	*grams.*	*grams.*	*grams.*	*grams.*	*cals.*	*cals.*
491	1.20[2]	68	17	54	8	185	21
577	1.24	72	21	63	17	200	36
5	1.23	55	4	46	0	167	3
...	1.11	57	6	52	6	177	13
Total...	....	252	48	215	31	729	73

[1]About 250 grams at the beginning of each hour of the first two periods.
[2]Sample included amount for about 3¾ hours, without food, preceding experiment.

RESPIRATION EXPERIMENTS.

J. J. C., 8h57m a. m. to 4h52m p. m., March 9, 1911. 64.3 kilograms.—Low-carbohydrate supper preceding day. Coffee made in proportion of two heaping tablespoonfuls of coffee to one cupful of water and boiled 10 minutes. Urinated 7h15m a. m. First basal period, awake and quiet; second, drowsy; third, very quiet, keeping awake with some difficulty; fourth, fell asleep at least once in spite of constant efforts of observer to prevent it. In periods following coffee, awake and quiet, with one decided movement in next to last period. Between sixth and seventh periods after coffee, turned on his side and generally somewhat active; between eighth and ninth periods, somewhat restless. Blood pressure: basal periods, 111, 110, 109, 110 mm.; after coffee, 123, 124, 117, 115, 117, 122, 129, 130,[1] 132 mm. Nitrogen in urine per hour 7h15m a. m. to 5 p. m., 0.43 gram.

[1]Single record.

J. J. C., 9h22m a. m. to 3h13m p. m., March 21, 1911. 64.8 kilograms.—Urinated at 7h15m a. m. and 3h35m p. m. First basal period, lay quietly; second, very quiet, asleep last two minutes; third, very sleepy; fourth, fell asleep and when aroused moved a little; fifth, still drowsy and coughed once. Between second and third periods after coffee, more active than usual; in fourth period after coffee, quiet but coughed once; fifth, very quiet but awake; last period, coughed twice. Blood pressure: basal periods, 118, 110, 115, 113, 111 mm.; after coffee, 118, 123, 117,[1] 122,[1] 125, 122[1] mm. Nitrogen in urine per hour 7h15m a. m. to 3h35m p. m., 0.43 gram.

L. E. E , 8h42m a. m. to 2 p. m., March 23, 1911. 59.5 kilograms.—High-carbohydrate diet preceding day. Urinated at 7h45m a. m. and 1h26m p. m. A little nervous in fourth period after coffee, twitching feet and making other slight movements. Blood pressure: basal periods, 120,[1] 126,[1] 110[1] mm.; after coffee, 126, 126, 130, 130, 129, 128, 130 mm. Nitrogen in urine per hour 7h45m a. m. to 1h26m p. m., 0.52 gram.

C. H. H., 2h40m p. m. to 3h50m p. m., March 24, 1911. 54.9 kilograms.—Preceded by water-drinking experiment (see table 76, page 146); for data regarding basal periods, see statistics for that experiment. Range in pulse rate between 2h24m p. m. and 2h34m p. m. (after drinking coffee), 65 to 73. Blood pressure: basal periods, 119, 122, 120, 120 mm.; after coffee, 115, 119, 119[1] mm. Nitrogen in urine per hour 8h15m a. m. to 4 p. m., 0.27 gram.

H. L. H., 8h30m a. m. to 12h21m p. m., March 25, 1911. 60.4 kilograms.—Low-carbohydrate diet day preceding. Urinated at 7h40m a. m. In last basal period, some difficulty in breathing, due to slight cold; coughed once. At end of second period after coffee, very slight leak in left nosepiece. Blood pressure: basal periods, 101, 101, 102 mm.; after coffee, 107, 106,[1] 117 mm. Nitrogen in urine per hour 7h40m a. m. to 12h30m p. m., 0.53 gram.

J. P. C., 12h10m p. m. to 2 p. m., March 27, 1911. 73.1 kilograms.—Preceded by water-drinking experiment (see table 77, page 146); for data regarding basal periods, see statistics for that experiment. Blood pressure: basal periods, 100, 102[1] mm.; after coffee, 105, 125, 110,[1] 116 mm. Nitrogen in urine per hour 11h53m a. m. to 2h15m p. m., 0.52 gram.

TABLE 82.—*J. J. C., March 9, 1911. Lying.* (Values per minute.)

Coffee, black (56.2° to 53.3° C.):
Amount, 325 grams; nitrogen, 0.28 gram; total energy, 45 cals.
Fuel value: Total, 43 cals.; from protein, 16 p. ct.; from carbohydrates, 84 p. ct.

Time.	Average respiration rate.	Carbon dioxide.	Respiratory quotient.	Oxygen.	Average pulse rate.	Heat (computed).
		c.c.		*c.c.*		*cals.*
Without food:						
Av. of 4 periods...	16	184	0.83	222	57	1.07
With food:[2]						
11h29m a.m.....	18	236	.96	246	65	1.23
11 55 a.m.....	20	222	.94	236	61	1.17
12 23 p.m.....	19	204	.82	250	58	1.21
12 53 p.m.....	19	196	.79	247	58	1.18
1 26 p.m.....	17	216	.81	266	61	1.28
1 59 p.m.....	19	200	.78	255	60	1.22
2 36 p.m.....	19	201	.78	257	57	1.23
3 55 p.m.....	18	193	.79	243	58	1.16
4 37 p.m.....	19	213	.79	268	59	1.28

[1]Single record. [2]Subject drank coffee between 11h21m and 11h23m a. m.

TABLE 83.—*J. J. C., March 21, 1911. Lying.* (Values per minute.)

Coffee:
Amount, 325 grams; nitrogen, 0.11 gram; total energy, 17 cals.
Fuel value: Total, 16 cals.; from protein, 18 p. ct.; from carbohydrates, 82 p. ct.

Time.	Average respiration rate.	Carbon dioxide.	Respiratory quotient.	Oxygen.	Average pulse rate.	Heat (computed).
		c.c.		*c.c.*		*cals.*
Without food:						
Av. of 5 periods...	17	192	0.83	232	64	1.12
With food:[1]						
12h07m p.m.....	21	228	.90	254	67	1.25
12 35 p.m.....	19	198	.84	236	63	1.14
1 04 p.m.....	20	215	.84	256	64	1.24
1 46 p.m.....	20	219	.84	261	65	1.27
2 27 p.m.....	21	215	.81	264	66	1.27
2 58 p.m.....	17	197	.78	253	62	1.21

[1]Subject drank coffee at 11h45m a. m.

TABLE 84.—*L. E. E., March 23, 1911. Lying.* (Values per minute.)

Coffee:
Amount, 325 grams; nitrogen, 0.09 gram; total energy, 17 cals.
Fuel value: Total, 16 cals; from protein, 16 p. ct.; from carbohydrates, 84 p. ct.

Time.	Average respiration rate.	Carbon dioxide.	Respiratory quotient.	Oxygen.	Average pulse rate.	Heat (computed).
		c.c.		*c.c.*		*cals.*
Without food:						
Av. of 3 periods...	11	204	0.86	236	58	1.15
With food:[1]						
10h31m a.m.....	12	214	.80	267	54	1.28
11 00 a.m.....	12	206	.82	251	52	1.21
11 29 a.m.....	11	215	.81	266	54	1.28
12 00 noon.....	12	212	.79	269	57	1.29
12 32 p.m.....	12	206	.77	268	54	1.28
1 06 p.m.....	11	214	.82	262	54	1.26
1 45 p.m.....	11	209	.78	269	55	1.28

[1]Subject drank coffee between 10h07m and 10h10m a. m.

TABLE 85.—*C. H. H., March 24, 1911. Lying.* (Values per minute.)

Coffee (60° C.):
Amount, 325 grams; nitrogen, 0.08 gram; total energy, 17 cals.
Fuel value: Total, 16 cals; from protein, 14 p. ct.; from carbohydrates, 86 p. ct.

Time.	Average respiration rate.	Carbon dioxide.	Respiratory quotient.	Oxygen.	Average pulse rate.	Heat (computed).
		c.c.		*c.c.*		*cals.*
Without food:						
Av. of 4 periods...	14	178	0.83	214	62	1.04
With food:[1]						
2h40m p.m.....	14	178	.79	226	65	1.08
3 10 p.m.....	14	185	.86	215	70	1.05
3 35 p.m.....	14	183	.85	215	70	1.05

[1]Subject drank coffee at 2h19m p. m.

TABLE 86.—*H. L. H., March 25, 1911. Lying.* (Values per minute.)

Coffee (60° C.):
Amount, 325 grams; nitrogen, 0.09 gram; total energy, 17 cals.
Fuel value: Total, 16 cals.; from protein, 16 p. ct.; from carbohydrates, 84 p. ct.

Time.	Average respiration rate.	Carbon dioxide.	Respiratory quotient.	Oxygen.	Average pulse rate.	Heat (computed).
		c.c.		*c.c.*		*cals.*
Without food:						
Av. of 3 periods...	12	202	0.83	244	65	1.18
With food:[1]						
10^h29^m a.m.....	15	214	.80	267	68	1.28
10 58 a.m.....	15	200	.76	263	65	1.25
11 31 a.m.....	16	212	.83	256	65	1.24
12 06 p.m.....	14	214	.80	268	69	1.29

[1]Subject drank coffee at 10^h07^m a. m.

TABLE 87.—*J. P. C., March 27, 1911. Lying.* (Values per minute.)

Coffee (52° C.):
Amount, 312 grams; nitrogen, 0.10 gram; total energy, 16 cals.
Fuel value: Total, 16 cals.; from protein, 16 p. ct.; from carbohydrates, 84 p. ct.

Time.	Average respiration rate.	Carbon dioxide.	Respiratory quotient.	Oxygen.	Average pulse rate.	Heat (computed).
		c.c.		*c.c.*		*cals.*
Without food:						
Av. of 2 periods...	18	188	0.86	219	52	1.07
With food:[1]						
12^h10^m p.m.....	20	191	.73	263	52	1.24
12 38 p.m.....	20	198	.86	231	51	1.13
1 10 p.m.....	21	194	.81	240	53	1.16
1 45 p.m.....	20	199	.81	246	54	1.18

[1]Subject drank coffee at 11^h38^m a. m.

DISCUSSION OF RESULTS OF COFFEE EXPERIMENTS.

As the coffee was taken hot in both of the calorimeter experiments, the same difficulties exist in making the proper correction for the changes in body-temperature that were indicated in the water-drinking experiments. With the subject A. H. M., in the calorimeter experiment of April 19, 1907, a positive increase in the heat production amounting to 11 per cent was noted. (See table 81.) Increments as great, if not greater, were shown in the carbon-dioxide production and oxygen consumption, thus confirming the fact that there was a true increase in the metabolism. In this case a relatively large amount of coffee, 1,011 grams, with 62 grams of sugar, was taken. That some of the increase in the metabolism may properly be ascribed to the sugar is clear from the data shown subsequently for the experiments in which the effect of ingesting cane sugar was studied.

In the experiment with A. W. W. on April 12, 1907, the amount of coffee taken was much smaller, only 271 grams; in addition, 23 grams of sugar were given. According to the data in table 80, there was an actual lowering of the metabolism (3 per cent), with practically no change in either the carbon-dioxide production or the oxygen consumption. To a certain extent, then, this experiment is similar to the experiments with hot water in which no material effect was observed on the metabolism. In fact, neither of these two experiments can be taken as giving positive evidence of an increase in the metabolism due to the ingestion of coffee.

The series of six respiration experiments with five subjects, all made in March 1911, gave more convincing results. (See tables 82 to 87.) In these experiments approximately 325 grams of coffee were taken with a temperature, so far as known, of 50° to 60° C. The increments averaged approximately 8 per cent, with a maximum of 13 per cent and a minimum of 2 per cent. These positive increments in the metabolism are distinctly at variance with the results of the calorimeter experiment with A. W. W., in which a slight decrease appeared. But the general trend is clear, and one may properly state that approximately 325 grams of coffee infusion at a temperature of about 60° C. will produce an increment in the metabolism of 8 to 9 per cent.

A careful analysis of the detailed data for these experiments shows that in practically all instances the increment was by no means at an end at the conclusion of the experiment; thus these figures probably represent low rather than high values. For example, in the experiment with J. J. C. on March 9, 1911, a basal metabolism of 222 c.c. of oxygen consumed was recorded. Over 5 hours later, at the end of the experiment, the oxygen consumption was 268 c.c. A similar long-continued effect was noted with the same subject on March 21, 1911. It is thus clear that the ingestion of coffee produces a positive increment in the

metabolism which must not be neglected in the interpretation of experiments in which it has been taken. It is conceivable that in the earlier experiments with diabetics reported from this laboratory by Benedict and Joslin the small amount of coffee taken by the subject one or two hours before the experiment may have been responsible for a part of the increase noted in the metabolism, although it was at that time specifically stated that the coffee could have no influence.[1] The amount of coffee taken by the diabetics was, however, less than half of the amount given in these experiments, and it was usually taken some time prior to the beginning of the observations. Since November 1914, no coffee has been used by the diabetic subjects on the morning of the experiment.

An examination of the pulse-rate data obtained in the coffee experiments shows slight increases after the ingestion of coffee for nearly all of the experiments, with usually a subsequent rapid fall to its previous level. In one experiment, that with L. E. E., March 23, 1911, the rate was lower after the coffee was taken.

The systolic blood pressure was higher in most instances after the coffee was drunk. The maximum rise was about 20 mm. mercury in the experiment with J. J. C. on March 9, 1911.

Experiments made by Edsall and Means[2] and Higgins and Means[3] on the effect of caffein have an interest in this connection, as they show clearly the influence upon the metabolism of this constituent of coffee. Two experiments were made by Edsall and Means in the Massachusetts General Hospital, both of which indicated a definite although not very great rise in the metabolism. Those made by Higgins and Means, and published from this laboratory, show that with one of the subjects, J. H. M., the gaseous metabolism was markedly increased. With H. L. H. there was also an increase in the metabolism, although this was slight.

We may conclude, therefore, that coffee, owing probably to its caffein content, acts as a stimulus to the metabolism, the increment with 325 grams of coffee infusion amounting on an average to 8 per cent for several hours. Experiments with caffein-free coffee would therefore have special interest.

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[1]Benedict and Joslin, Carnegie Inst. Wash. Pub. No. 136, 1910, p. 216.
[2]Edsall and Means, Arch. Intern. Med., 1914, **14**, p. 897.
[3]Higgins and Means, Journ. Pharm. and Exp. Therapeutics, 1915, **7**, p. 1.

INGESTION OF BEEF TEA.

The noticeable increase in metabolism found by the earlier investigators as a result of the ingestion of flesh led to tests on animals to determine the influence of extracts which consist chiefly of creatine and its allied compounds. Experiments with man on this subject are extremely limited in number. Beef extract (probably 15 per cent water) in amounts of 12 to 18 grams per day was used in some of the classical experiments of Pettenkofer and Voit[1] on their so-called fasting days, but as no suitable basal value is available for comparison the results of the experiments give no evidence as to the possible effect of the extract upon the metabolism. In our study on the influence of the ingestion of food, a study was also made of the effect of ingesting beef tea.

STATISTICS OF EXPERIMENTS.

The series of experiments on beef tea included five experiments with the respiration calorimeter at Middletown (see tables 88 to 92) and two experiments with the chair calorimeter at Boston (see tables 93 and 94). In addition, six experiments were made with the universal respiration apparatus in Boston (see tables 95 to 100). The results of these experiments are summarized in tables 67 and 68. (See pages 135 and 136.)

For the calorimeter experiments the beef tea was made by extracting fresh beef with water; in all but one of the respiration experiments it was prepared from a so-called extract of beef, a commercial product being used. The composition of the beef tea is indicated in table 50. (See page 124.) The method of preparation from the fresh beef was as follows:

The beef (from the top of the round) was freed so far as possible from all visible fat and connective tissue, then chopped and covered with cold water to extract the juices; finally both meat and liquid were heated slowly to about 80° C. For a few experiments it was heated only to 40° C. The liquid was carefully filtered to remove the solid material and then cooled. To prepare it for the experiment the solidified fat was removed, and the remainder reheated to approximately 80° C. Salt was added to taste by the subject.

It is obvious that beef tea, prepared from either the fresh meat or the extract, would contain considerable amounts of creatine and creatinine.[2] In some instances the analyses showed a large proportion of nitrogen, particularly in the experiment of May 9, 1907, in which 6.82

[1]Pettenkofer and Voit, Zeitschr. f. Biol., 1866, 2, p. 459.

[2]The amount of creatine and creatinine in the beef tea used in the Middletown experiments was determined through the kindness of Dr. Victor C. Myers, at that time assistant pathologist at the Connecticut Hospital for the Insane and at present director of the Laboratory of Pathological Chemistry in the New York Post-Graduate Medical School and Hospital.

grams of nitrogen were taken in 1,605 grams of beef tea. Thus the beef tea, particularly that made from the fresh beef, did not consist wholly of extractives, but in all probability it contained an appreciable amount of protein. Accordingly, we must also consider here the possibility of a true protein ingestion.

In a few of the calorimeter experiments the beef tea was given to the subject cold, but usually it was taken hot; the temperature of the liquid is recorded for each experiment in the statistical tables, also in the summary tables. In the respiration experiments, much smaller amounts were given than in the calorimeter experiments and the temperature was usually between 50° and 60° C. The total increment in the metabolism was computed for the respiration experiments by the planimeter method as described in the section on the ingestion of coffee. (See page 151.) Statistical data not included in the tables or in the discussion are given in the following paragraphs for all of the experiments. In this and subsequent statistics, the times given include both basal and food periods if the basal values were determined immediately before the ingestion of the food.

CALORIMETER EXPERIMENTS.

E. H. B., 8h27m a. m. to 4h27m p. m., April 8, 1907. 72.9 kilograms.—Urinated 6h50m a. m. and 4h27m p. m.; took enema about 7h15m a. m. More or less activity in first period in connection with receiving beef tea and dishes, as subject was obliged to go to food aperture several times. Very quiet in last part of first period and in second period, but not so quiet in fourth period. Reading greater part of time; occasionally drowsy. Drank 134 grams water in fourth period. Body-temperature: 36.57°, 36.50°, 36.57°, 36.61°, and 36.66° C. Pulse rate, 51; respiration rate, 18. Beef tea heated to about 80° C. in preparation. Creatinine in beef tea, 0.0121 gram in 100 c.c.; creatine,[1] 0.109 gram in 100 c.c.

A. H. M., 8h44m a. m. to 4h44m p. m., April 29, 1907. 67.4 kilograms.—Urinated 6, 9h47m, 10h54m a. m., 2h53m and 5h20m p. m. Somewhat restless in first and third periods; more quiet in second and fourth periods; much of time reading. Body-temperature: 36.70°, 36.51°, 36.38°, 36.22°, and 36.42° C. Pulse rate, 60; respiration rate, 20.

A. W. W., 8h24m a. m. to 4h24m p. m., May 2, 1907. 58.4 kilograms.—Urinated 7h10m, 9h40m, 10h32m a. m., 12h28m, 2h32m, and 4h35m p. m. Felt cold after taking both portions of beef tea. Considerable activity in telephoning and getting beef tea from food aperture, but after 9h06m a. m. subject sat quietly and read; very quiet in other periods. Drank water at beginning of fourth period (30 grams). Body-temperature: 36.41°, 36.60°, 36.64°, 36.76°, and 36.75° C. Pulse rate, 61; respiration rate, 20. Creatinine in beef tea, 0.011 gram in 100 c.c.; creatine,[1] 0.161 gram in 100 c.c.

A. W. W., 8h25m a. m. to 4h25m p. m., May 9, 1907. 58.8 kilograms.—Urinated 7h10m a. m. (after enema), 12h32m and 4h34m p. m. Very quiet in first period after 9 o'clock, also in second and fourth periods; in third period, somewhat more active. Perspired very freely for a short time after drinking beef tea. Drank water at beginning of both second and third periods (216

[1]Expressed as creatinine.

grams). Body-temperature: 36.62°, 36.75°, and 36.88° C. Pulse rate, 62; respiration rate, 21. Beef tea used was of double strength and not heated above 40° C. in making. Coagulated somewhat when reheated to about 75° C. before serving. Creatinine in beef tea, 0.018 gram in 100 c.c.; creatine,[1] 0.211 gram in 100 c.c.

A. H. M., 8h24m a. m. to 4h24m p. m., May 10, 1907. 66.7 kilograms.—Beef tea used for this experiment same as that used for A. W. W., May 9, 1907, but not heated to so high a temperature for serving; no coagulation. Subject urinated 7, 10h28m a. m., 12h36m and 4h32m p. m. Very quiet, read greater part of time. Telephoned and opened food aperture at 8h32m a. m. Body-temperature: 36.62°, 36.51°, 36.49°, 36.74°, and 36.68° C. Pulse rate, 59; respiration rate, 18.

J. J. C., 9h02m a. m. to 3h49m p. m., May 12, 1910. 64.7 kilograms.—Urinated at 6h55m, 9h11m, 11h04m, 11h53m a. m. and 1h15m p. m. Slept considerable part of experiment; slept 10 minutes in first basal period, 10 minutes in second period, and about half of first period after beef tea. Awakened by observer and to prevent his falling asleep again was told to ring telephone bell every 5 minutes as evidence of being awake. Fell asleep at 1h12m p. m. (in third period after beef tea), also at 3h44m p. m. (in fifth period). Moved considerably at 1h43m p. m. Basal periods: body-temperature, 36.81°, 36.57°, 36.58° C.; pulse rate, 64; respiration rate, 19. Periods after beef tea: body-temperature, 36.85°, 36.81°, 36.85°, 36.79°, and 36.71° C.; pulse rate, 65; respiration rate, 20. Both pulse and respiration records are lacking for a part of the experiment.

J. R., 8h57m a. m. to 3h32m p. m., May 13, 1910. 69.5 kilograms.—Took enema before entering apparatus. During basal periods telephoned once; at end of second period complained of pain in stomach. After taking beef tea, had nausea and drank water (28 grams). During periods after beef tea did not feel well; was restless, telephoned several times, drank water (37 grams) in first period, urinated in second period and again at 3h40m p. m. (after experiment). Basal periods: pulse rate, 65; respiration rate, 15. Periods after beef tea: pulse rate, 68; respiration rate, 16.

TABLE 88.—*E. H. B., April 8, 1907. Sitting.* (2-hour periods.)

Beef tea (82.5° C.):
Amount, 892 grams; nitrogen, 1.61 grams; total energy, 71 cals.
Fuel value: Total, 57 cals.; from protein, 72 p. ct.; from fat, 15 p. ct.; from carbohydrates, 13 p. ct.
Nitrogen in urine, 0.72 gram per 2 hours.[2]
Basal values (March 7 and 13, 1907): CO_2, 58 grams; O_2, 48 grams; heat, 179 cals.

Time elapsed since subject finished eating.	Carbon dioxide.		Oxygen.		Heat.	
	Total.	Increase.	Total.	Increase.	Total.	Increase.
	grams.	*grams.*	*grams.*	*grams.*	*cals.*	*cals.*
0 to 2 hours[3]..	63	5	56	8	182	3
2 to 4 hours...	57	−1	47	−1	182	3
4 to 6 hours...	56	−2	49	1	171	−8
6 to 8 hours...	56	−2	48	0	170	−9
Total...	232	0	200	8	705	−11

[1]Expressed as creatinine.
[2]Sample included amount for about 1¾ hours, without food, preceding experiment.
[3]Subject drank beef tea in 17 minutes, finishing 25 minutes after the beginning of this period.

TABLE 89.—*A. H. M., April 29, 1907. Sitting.* (2-hour periods.)

Beef tea (22° C.):
Amount, 1,143 grams; nitrogen, 2.78 grams; total energy, 116 cals.
Fuel value: Total, 91 cals.; from protein, 79 p. ct.; from fat, 11 p. ct.; from carbohydrates, 10 p. ct.

Basal values (March 6 and 9, 1907): CO_2, 51 grams; O_2, 46 grams; heat, 164 cals. Nitrogen in urine, 1.06 grams per 2 hours (April 29, 1907).

Time elapsed since subject finished eating.	Nitrogen in urine per 2 hours.	Carbon dioxide.		Oxygen.		Heat.	
		Total.	Increase.	Total.	Increase.	Total.	Increase.
	grams.	*grams.*	*grams.*	*grams.*	*grams.*	*cals.*	*cals.*
0 to 2 hours[1]..	1.54[2]	62	11	51	5	182	18
2 to 4 hours..	1.11	54	3	50	4	165	1
4 to 6 hours..	1.11	51	0	46	0	158	−6
6 to 8 hours..	.93	52	1	44	−2	164	0
Total...	....	219	15	191	7	669	13

[1]Subject finished drinking beef tea 14 minutes after the beginning of this period. The drinking occupied 12 minutes.
[2]Computed from amount for 67 minutes in latter portion of period.

TABLE 90.—*A. W. W., May 2, 1907. Sitting.* (2-hour periods.)

Beef tea (1,413 grams, 22° C.; 643 grams, 7° C.):
Amount, 2,056 grams; nitrogen, 4.27 grams; total energy, 185 cals.
Fuel value: Total, 148 cals.; from protein, 75 p. ct.; from fat, 13 p. ct.; from carbohydrates, 12 p. ct.

Basal values (March 15 and 21, 1907): CO_2, 50 grams; O_2, 41 grams; heat, 155 cals. Nitrogen in urine, 0.81 gram per 2 hours (May 2, 1907).

Time elapsed since subject finished eating.	Nitrogen in urine per 2 hours.	Carbon dioxide.		Oxygen.		Heat.	
		Total.	Increase.	Total.	Increase.	Total.	Increase.
	grams.	*grams.*	*grams.*	*grams.*	*grams.*	*cals.*	*cals.*
0 to 2 hours[1]..	1.04[2]	62	12	53	12	191	36
2 to 4 hours..	0.17	52	2	36	−5	136	−19
4 to 6 hours..	1.35	50	0	43	2	150	−5
6 to 8 hours..	1.17	50	0	40	−1	147	−8
Total...	....	214	14	172	8	624	4

[1]Subject finished drinking beef tea 38 minutes after the beginning of this period. The drinking occupied 15 minutes.
[2]Computed from amount for 52 minutes in latter portion of period.

TABLE 91.—*A. W. W., May 9, 1907. Sitting.* (2-hour periods.)

Beef tea (54° C.):
Amount, 1,605 grams; nitrogen, 6.82 grams; total energy, 264 cals.
Fuel value: Total, 204 cals.; from protein, 86 p. ct.; from fat, 7 p. ct.; from carbohydrates. 7 p. ct.
Basal values (March 15 and 21, 1907): CO_2, 50 grams; O_2, 41 grams; heat, 155 cals.

Time elapsed since subject finished eating.	Nitrogen in urine per 2 hours.	Carbon dioxide.		Oxygen.		Heat.[1]	
		Total.	Increase.	Total.	Increase.	Total.	Increase.
	grams.	*grams.*	*grams.*	*grams.*	*grams.*	*cals.*	*cals.*
0 to 2 hours[2]..	1.36[3]	63	13	51	10	170	15
2 to 4 hours..	1.36[3]	59	9	43	2	169	14
4 to 6 hours..	1.18	53	3	36	−5	151	−4
6 to 8 hours..	1.18	51	1	43	2	152	−3
Total...	....	226	26	173	9	642	22

[1]Heat eliminated corrected for change in body-weight, but not for change in body-temperature.
[2]Subject finished drinking beef tea 33 minutes after beginning of this period. The drinking occupied 18 minutes.
[3]Sample included amount for 1¼ hours, without food, preceding experiment.

TABLE 92.—*A. H. M., May 10, 1907. Sitting.* (2-hour periods.)

Beef tea (50° C.):
Amount, 892 grams; nitrogen, 3.79 grams; total energy, 147 cals.
Fuel value: Total, 113 cals.; from protein, 86 p. ct.; from fat, 7 p. ct.; from carbohydrates, 7 p. ct.
Basal values (March 6 and 9, 1907): CO_2, 51 grams; O_2, 46 grams; heat (computed), 152 cals.

Time elapsed since subject finished eating.	Nitrogen in urine per 2 hours.	Carbon dioxide.		Oxygen.		Heat (computed.)	
		Total.	Increase.	Total.	Increase.	Total.	Increase.
	grams.	*grams.*	*grams.*	*grams.*	*grams.*	*cals.*	*cals.*
0 to 2 hours[1]..	1.62[2]	65	14	54	8	182	30
2 to 4 hours..	1.59	53	2	42	−4	141	−11
4 to 6 hours..	1.19	54	3	50	4	165	13
6 to 8 hours..	1.19	52	1	41	−5	140	−12
Total...	....	224	20	187	3	628	20

[1]Subject finished drinking beef tea 20 minutes after the beginning of this period. The drinking occupied 8 minutes.
[2]Sample included amount for about 1½ hours, without food, preceding experiment.

TABLE 93.—*J. J. C., May 12, 1910. Sitting.* (1-hour periods.)

Beef tea (*932 grams, 15.5° C.; 290 grams, 38° C.*):
Amount, 1,222 grams; nitrogen, 5.62 grams; total energy, 214 cals.
Fuel value: Total, 165 cals.; from protein, 87 p. ct.; from fat, 7 p. ct.; from carbohydrates, 6 p. ct.
Nitrogen in urine, 1.03 grams per hour (in first two periods).[1]
Basal values (May 12, 1910): CO_2, 25 grams; O_2, 20 grams; heat,[2] 79 cals.; respiratory quotient, 0.92. Nitrogen in urine, 0.34 gram per hour.

Time elapsed since subject finished eating.	Carbon dioxide.		Oxygen.		Heat.[2]		Respiratory quotient.
	Total.	Increase.	Total.	Increase.	Total.	Increase.	
	grams.	*grams.*	*grams.*	*grams.*	*cals.*	*cals.*	
½ to 1½ hours.....	30.5	5.5	25.0	5.0	79	0	0.90
1½ to 2½ hours.....	28.5	3.5	25.5	5.5	84	5	.82
2½ to 3½ hours.....	27.5	2.5	23.5	3.5	76	−3	.85
3½ to 4½ hours.....	25.0	0.0	22.5	2.5	76	−3	.80
Total.....	111.5	11.5	96.5	16.5	315	−1	....

[1]Sample obtained previous to these periods, but also following the ingestion of beef tea, contained 0.85 gram nitrogen per hour.
[2]Heat eliminated corrected for change in body-weight, but not for change in body-temperature.

TABLE 94.—*J. R., May 13, 1910. Sitting.* (1-hour periods.)

Beef tea (*44.1° C.*):
Amount, 314 grams; nitrogen, 1.26 grams; total energy, 48 cals.
Fuel value: Total, 37 cals.; from protein, 86 p. ct.; from fat, 7 p. ct.; from carbohydrates, 7 p. ct.
Basal values: CO_2, 26 grams (May 13, 1910); O_2, 22.5 grams (March 21 to May 13, 1910); heat,[1] 80 cals. (May 13, 1910).

Time elapsed since subject finished eating.	Nitrogen in urine per hour.	Carbon dioxide.		Oxygen.		Heat.[1]		Respiratory quotient.
		Total.	Increase.	Total.	Increase.	Total.	Increase.	
	gram.	*grams.*	*grams.*	*grams.*	*grams.*	*cals.*	*cals.*	
½ to 1½ hours.	0.53[2]	29.0	3.0	24.0	1.5	81	1	0.87
1½ to 2½ hours.	.59	26.5	.5	24.5	2.0	78	−2	.79
2½ to 3½ hours.	.59	26.0	.0	23.0	0.5	76	−4	.81
3½ to 4½ hours.	.59	26.0	.0	24.0	1.5	77	−3	.78
Total...	....	107.5	3.5	95.5	5.5	312	−8	....

[1]Heat eliminated corrected for change in body-weight, but not for change in body-temperature.
[2]Sample included amount for 3½ hours, without food, preceding drinking of beef tea.

RESPIRATION EXPERIMENTS.

J. J. C., 8h59m a. m. to 3h40m p. m., January 25, 1911. 64.3 kilograms.—Was awake throughout first basal period, but very sleepy and quiet; slept about half of second period, and asleep part of third period. In periods after beef tea, slept part of first and second periods, awake throughout third period, slept much of time in fourth period in spite of efforts to keep him awake; coughed once and jumped at a sudden noise in the room; awake in fifth and sixth periods, sleepy in seventh period, and slept between seventh and eighth periods; awake in eighth and ninth periods and very quiet. Nitrogen in urine per hour 7 a. m. to 3h40m p. m., 0.50 gram.

V. G., 8h41m a. m. to 4h51m p. m., January 26, 1911. 55.0 kilograms.—Awake and quiet in first basal period, sleepy in second, very sleepy in third period; was awakened several times and did not sleep more than 2 minutes at any time. After beef tea, awake in all periods and for most part quiet; very quiet in seventh period after beef tea; coughed twice in first period, twice in second period; slight leak in nosepieces in eighth period. Nitrogen in urine per hour 7h45m a. m. to 4h55m p. m., 0.39 gram.

C. H. H., 9 a. m. to 4h42m p. m., January 27, 1911. 55.2 kilograms.—Had walked 1.25 miles since 5 p. m. the day before (pedometer record). Awake and quiet both basal periods and periods after beef tea. A desire to urinate in eighth period after beef tea, but no discomfort. Blood pressure: basal periods, 107, 109, 113 mm.; periods after beef tea, 106, 101, 96, 98, 101, 113, 114, 115, 107 mm. Nitrogen in urine per hour 7h20m a. m. to 4h55m p. m., 0.45 gram.

C. H. H., 9 a. m. to 4h45m p. m., February 2, 1911. 54.5 kilograms.—Between 5h15m p. m., February 1, and 8 a. m., February 2, subject walked 3.6 miles (pedometer record); amount of activity probably greater, as subject skated 2 hours during evening preceding experiment. Awake and very quiet throughout basal and food periods. Blood pressure: basal periods, 107, 106, 105 mm.; periods after beef tea, 120, 112, 106, 105, 114, 114, 112, 112, 112 mm. Nitrogen in urine per hour 8h15m a. m. to 4h55m p. m., 0.40 gram.

V. G., 8h45m a. m. to 5h01m p. m., February 3, 1911. 54.8 kilograms.—Walked 3.9 miles between 5 p. m. February 2 and 8 a. m. February 3 (pedometer record). Awake and very quiet in first basal period, fell asleep once or twice in second period, but was immediately wakened. Beef tea produced nausea; subject unable to drink all provided. After beef tea, awake and quiet in first period, slept in second period a little; impossible to keep him awake continuously in third period, even with frequent ringing of an electric bell; in this period moved slightly in sleep and pneumograph slipped out of position. In fourth period, slept very little, if any, and was awake and quiet in fifth and sixth periods; fell asleep again for 3 or 4 minutes in seventh period. In four last periods awake and quiet for most part, but slept some in ninth period. Blood pressure: basal periods, 93, 96 mm.; periods after beef tea, 93, 100, 99, 104, 102, 105, 94, 99, 93, 100, 97 mm. Nitrogen in urine per hour 7h45m a. m. to 5h12m p. m., 0.31 gram.

C. H. H., 9h03m a. m. to 4h55m p. m., February 8, 1911. 55.1 kilograms.—Very quiet and awake throughout basal and food periods. Fourth period was shortened to 11 minutes owing to slipping of nosepieces, which caused a leak. Blood pressure: basal periods, 107, 97, 95 mm.; periods after beef tea, 100, 104, 111, 111, 107, 106, 108, 107 mm. Nitrogen in urine per hour 8h15m a. m. to 5h12m p. m., 0.49 gram.

TABLE 95.—*J. J. C., January 25, 1911. Lying.* (Values per minute.)

Beef tea (53° to 60° C.):
Amount, 400 grams; nitrogen, 1.56 grams; total energy, 61 cals.
Fuel value: Total, 47 cals.; from protein, 85 p. ct.; from fat, 8 p. ct.; from carbohydrates, 7 p. ct.

Time.	Average respiration rate.	Carbon dioxide.	Respiratory quotient.	Oxygen.	Average pulse rate.	Heat (computed).
Without food:		*c.c.*		*c.c.*		*cals.*
Av. of 3 periods...	17	196	0.86	229	64	1.12
With food:[1]						
10^h51^m a.m.....	21	222	.90	248	73	1.22
11 16 a.m.....	18	226	.88	257	67	1.26
11 42 a.m.....	21	227	.95	240	72	1.20
12 13 p.m.....	19	227	.86	263	71	1.28
12 38 p.m.....	20	220	.79	278	68	1.33
1 04 p.m.....	21	220	.86	256	68	1.25
1 30 p.m.....	19	214	.84	254	68	1.23
2 33 p.m.....	22	219	.82	267	72	1.29
2 58 p.m.....	22	215	.84	256	77	1.24
3 25 p.m.....	22	217	.79	274	77	1.31

[1]Subject drank beef tea at 10^h43^m a. m.

TABLE 96.—*V. G., January 26, 1911. Lying.* (Values per minute.)

Beef tea (55.2° to 53.6° C.):
Amount, 400 grams; nitrogen, 1.45 grams; total energy, 57 cals.
Fuel value: Total, 44 cals.; from protein, 84 p. ct.; from fat, 8 p. ct.; from carbohydrates, 8 p. ct.

Time.	Average respiration rate.	Carbon dioxide.	Respiratory quotient.	Oxygen.	Average pulse rate.	Heat (computed).
Without food:		*c.c.*		*c.c.*		*cals.*
Av. of 3 periods...	20	188	0.84	225	53	1.09
With food:[1]						
10^h42^m a.m.....	19	202	.84	241	67	1.17
11 15 a.m.....	21	213	.90	237	65	1.17
11 46 a.m.....	20	196	.87	226	61	1.10
12 18 p.m.....	20	190	.82	231	58	1.11
12 48 p.m.....	20	214	.87	247	62	1.21
1 23 p.m.....	20	213	.86	248	60	1.21
2 29 p.m.....	18	202	.84	240	58	1.16
3 25 p.m.....	19	206	.83	249	59	1.20
4 36 p.m.....	20	209	.82	255	60	1.23

[1]Subject drank beef tea between 10^h21^m and 10^h26^m a. m.

TABLE 97.—*C. H. H., January 27, 1911. Lying.* (Values per minute.)

Beef tea (52.8° to 52.0° C.):
Amount, 400 grams; nitrogen, 1.44 grams; total energy, 57 cals.
Fuel value: Total, 44 cals.; from protein, 84 p. et.; from fat, 8 p. et.; from carbohydrates, 8 p. et.

Time.	Average respiration rate.	Carbon dioxide.	Respiratory quotient.	Oxygen.	Average pulse rate.	Heat (computed).
Without food:		*c.c.*		*c.c.*		*cals.*
Av. of 3 periods...	15	174	0.84	206	61	1.00
With food:[1]						
10^h55^m a.m.....	15	180	.84	214	62	1.04
11 26 a.m.....	15	186	....	...	62	1.05
11 54 a.m.....	15	184	.88	210	62	1.03
12 27 p.m.....	14	182	.85	214	59	1.04
12 56 p.m.....	14	173	.81	214	58	1.03
2 18 p.m.....	14	188	.85	220	61	1.07
2 58 p.m.....	14	172	.81	212	60	1.02
3 52 p.m.....	14	183	.82	224	62	1.08
4 27 p.m.....	15	180	.85	212	61	1.03

[1]Subject drank beef tea between 10^h46^m and 10^h50^m a. m.

TABLE 98.—*C. H. H., February 2, 1911. Lying.* (Values per minute.)

Beef tea (61.4° to 59.0° C.):
Amount, 400 grams; nitrogen, 1.46 grams; total energy, 57 cals.
Fuel value: Total, 44 cals.; from protein, 84 p. et.; from fat, 8 p. et.; from carbohydrates, 8 p. et.

Time.	Average respiration rate.	Carbon dioxide.	Respiratory quotient.	Oxygen.	Average pulse rate.	Heat (computed).
Without food:		*c.c.*		*c.c.*		*cals.*
Av. of 3 periods...	15	169	0.82	206	65	0.99
With food:[1]						
10^h48^m a.m.....	15	164	.76	215	69	1.02
11 14 a.m.....	14	180	.80	225	68	1.08
11 53 a.m.....	16	186	.85	218	68	1.06
12 25 p.m.....	16	177	.78	227	67	1.08
1 12 p.m.....	15	176	.77	228	65	1.09
2 03 p.m.....	15	170	.79	214	66	1.02
2 52 p.m.....	15	164	.76	215	65	1.02
4 04 p.m.....	15	172	.80	214	64	1.03
4 30 p.m.....	16	173	.78	223	64	1.07

[1]Subject drank beef tea between 10^h36^m and 10^h40^m a. m.

TABLE 99.—*V. G., February 3, 1911. Lying.* (Values per minute.)

Beef tea (58.7° to 60.0° C.):
Amount, 269 grams; nitrogen, 0.98 gram; total energy, 38 cals.
Fuel value: Total, 30 cals.; from protein, 84 p. ct.; from fat, 9 p. ct.; from carbohydrates, 7 p. ct.

Time.	Average respiration rate.	Carbon dioxide.	Respiratory quotient.	Oxygen.	Average pulse rate.	Heat (computed).
Without food:		c.c.		c.c.		cals.
Av. of 2 periods...	19	178	0.79	224	58	1.07
With food:[1]						
10^h24^m a.m.....	19	181	.78	233	61	1.11
10 52 a.m.....	20	193	.79	245	63	1.17
11 29 a.m.....	19	195	.83	235	59	1.14
12 02 p.m.....	19	195	.80	244	60	1.17
12 36 p.m.....	18	195	.80	244	59	1.17
1 05 p.m.....	19	202	.80	254	63	1.22
1 53 p.m.....	19	193	.78	247	61	1.18
2 33 p.m.....	19	198	.80	247	60	1.19
3 09 p.m.....	21	185	.74	249	59	1.18
4 21 p.m.....	20	205	.82	250	63	1.21
4 46 p.m.....	20	206	.81	254	62	1.22

[1]Subject drank beef tea between 10^h10^m and 10^h13^m a. m.

TABLE 100.—*C. H. H., February 8, 1911. Lying.* (Values per minute.)

Beef tea (55.4° to 50.0° C.):
Amount, 350 grams; nitrogen, 4.30 grams; total energy, 54 cals.
Fuel value: Total, 41 cals.; from protein, 84 p. ct.; from fat, 9 p. ct.; from carbohydrates, 7 p. ct.

Time.	Average respiration rate.	Carbon dioxide.	Respiratory quotient.	Oxygen.	Average pulse rate.	Heat (computed).
Without food:		c.c.		c.c.		cals.
Av. of 3 periods...	14	173	0.82	210	65	1.01
With food:[1]						
12^h08^m p.m.....	14	179	.85	210	68	1.02
12 36 p.m.....	14	187	.83	224	71	1.08
1 08 p.m.....	14	195	.86	228	70	1.11
1 39 p.m.....	16	194	....	...	70	1.07
2 13 p.m.....	14	192	.91	212	69	1.05
2 49 p.m.....	14	191	.87	219	68	1.07
3 28 p.m.....	15	179	.81	222	66	1.07
4 40 p.m.....	14	182	.82	221	70	1.07

[1]Subject drank beef tea between 11^h54^m and 12 a. m.

DISCUSSION OF RESULTS OF BEEF-TEA EXPERIMENTS.

An examination of the summary of values given for the calorimeter experiments in table 67 (see page 135) shows that there was but little or no increase in the heat output in these experiments. The maximum increment was that on May 9, 1907, of 4 per cent. Furthermore, the figures show no variation as a result of the differences in the temperature of the beef tea, nor is there an apparent correlation between the total nitrogen content of the beef tea and the heat increment.

The beef tea for the respiration experiments, the results of which are summarized in table 68, was made from beef extract in all cases except for the experiment with C. H. H. on February 8, 1911. In practically every experiment there was a perceptible increase in the metabolism, the maximum being that in the experiment with J. J. C., on January 25, 1911, namely, 12 per cent. The average increment was not far from 8 per cent, a result strikingly at variance with that found in the calorimeter experiments. This is all the more significant as comparatively small amounts were given in the respiration experiments (never more than 400 grams), while in the calorimeter experiments, if we exclude that with J. R., the amount ingested ranged from 892 grams to 2,056 grams. As further evidence of the positive increase noted in the respiration experiments, an examination of the detailed results given in tables 95 to 100 shows that the increment in the oxygen consumption was usually still present at the end of the experiment, *i. e.*, the metabolism had not reached the basal level. The values for the total increment here recorded are therefore for the most part smaller than would have been obtained had the experiment been continued.

The most striking result obtained in these experiments is the very small reaction to the beef tea shown by the subject C. H. H., this being much less than in any of the other respiration experiments in the series. This man was a particularly satisfactory subject with the respiration apparatus, as he lay without movement for hours at a time and showed an unusually clear understanding of the requirements of a coöperating subject. The high values obtained with J. J. C. and V. G. can probably be ascribed to their tendency towards restlessness and lack of coöperation. In any event the results of these respiration experiments appear to show that beef tea, when prepared from the so-called commercial extract of beef, has an influence on the metabolism. This effect in certain of the experiments was fairly long continued and amounted at times to an increase of heat approximately 8 to 10 per cent above the basal value.

The pulse rate was affected to a slight extent in the calorimeter experiments in Boston. Only two of the experiments with the respiration apparatus show significant increases in pulse rate, these being the experiment with C. H. H., February 8, 1911, in which the rate rose

from 65 per minute to a maximum of 71, and the experiment with V. G., January 26, 1911, in which the pulse rate changed from an average of 53 per minute to 67 to 60 per minute after the beef extract was taken.

The systolic blood pressure was measured in the experiment with V. G., February 3, 1911, and in the three experiments with C. H. H. In none of them was there a marked change in the blood pressure.

While beef extract has an effect upon the metabolism, its influence is so small that moderate amounts may be given to individuals in a fasting condition without materially increasing the basal value. Since it is highly desirable to secure a diet which will not materially raise the basal metabolism and yet will prevent the sensations of hunger frequently experienced by patients when the breakfast is omitted, it may be perfectly legitimate to use a moderate amount of beef extract in experiments with pathological cases even when determining the so-called basal value prior to observations. Special tests on this point should be made before beef extract is used in this way.

In considering the influence of beef tea and other liquids upon the metabolism, the results obtained in the experiments on water-drinking should naturally be taken into consideration. A careful analysis of these experiments shows that the drinking of water was, in all but two instances, without effect upon the metabolism. On the other hand, the fact that increments were obtained in these two experiments, one of which—an extremely well-conducted and satisfactory experiment—showed an increment of 16 per cent in the metabolism after 1,800 grams of water,[1] must lead one to be somewhat cautious in the interpretation of results of experiments in which liquids are ingested. But the experimental data thus far obtained for beef tea may properly lead to the conclusion that with amounts of 400 grams or more a perceptible increase in the metabolism may be expected.

[1]See experiment with T. M. C. on January 12, 1911 (table 72, p. 144.)

INGESTION OF CARBOHYDRATES.

In the historical development of the study on the influence of food upon the metabolism the first observations in which demonstrable increases could be determined were those with protein. These increases were so large that it was not at all strange that observers expected to find a considerable rise in the metabolism with both fat and carbohydrates. Accordingly, when a much smaller increment in the metabolism was found with carbohydrates than that obtained in experiments with protein, the influence of the former class of nutrients was without doubt given less consideration than it should have been.

The actual importance of the increases with carbohydrates may have been obscured by several causes. First, the effect of carbohydrate ingestion persists for a much shorter time than that following the ingestion of protein; hence, in the experimental period first used (24 hours) the increase in the metabolism in the hours immediately following the taking of the carbohydrate food may have disappeared when the values for the essentially basal metabolism in the later hours of the day were included; in other words, the "peak" effect of the carbohydrate ingestion was lost as a result of the lengthening of the experimental period.

Secondly, it has frequently happened that the basal value was determined in 24 hours, or even longer, of complete starvation. Experiments have shown[1] that during a period of this length without food there is a very considerable draft upon the carbohydrate storage in the body; consequently when carbohydrate is afterwards ingested, the body attempts first to replenish the store of this material. The effect on the metabolism due to the ingestion of food is thus considerably lessened by the fact that the carbohydrate is in large part not burned, but simply stored as glycogen.

In Rubner's experiment on man[2] (and in this monograph we are dealing entirely with experiments on man) a series of experiments on 5 consecutive days was carried out. On the first day the subject fasted and did no work; on the second day he was given protein without work; on the third day protein with work; on the fourth day sugar without work; and on the fifth day sugar with work. Considering specifically the fourth day, when sugar was given without work, we find that the heat output per 24 hours was 2,023 calories as compared with a basal value of 1,976 calories, an increment of only 47 calories. A close examination of the experimental procedure shows that the 3 days prior to the sugar day, *i. e.*, a day of hunger, a day with protein, and a day with protein and work, all contributed toward the depletion of the glycogen supply in the body, and it is not surprising that no larger increment in the metabolism was found.

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[1]Johansson, Skand. Arch. f. Physiol., 1909, **21,** p. 1. See, also, p. 70 of this monograph.
[2]Rubner, Sitzber. K. Preuss. Akad. Wiss., 1910, p. 316.

It is surprising, however, that according to the method of computing the energy used by Rubner at that time, it was assumed that the carbohydrates were first burned. As the 600 grams of cane sugar given on that day correspond to an energy consumption of approximately 2,400 calories, or more than was actually measured, it is presumable that the 2,023 calories given by Rubner as the value for the heat output is based upon the assumption that the combustion for the day was entirely of pure carbohydrate. This amount of energy would be produced by the combustion of approximately 510 grams of sugar. It is well known that 50 to 100 or more grams of glycogen may be withdrawn on the first day of fasting. It is quite likely, therefore, that an appreciable portion of the sugar ingested may have been used to form glycogen and not to contribute to the increased metabolism measured by Rubner.

Rubner's calculations are seriously hampered by the absence of data regarding the oxygen consumption, which would contribute more directly to the computation of the total energy transformations. The increment in the carbon-dioxide production has been more employed for such researches as these than any other factor. Even when used in special studies like those of Johansson and Gigon,[1] an attempt to explain the processes on the basis of this increment immediately results in great confusion. A typical case will serve to illustrate this.

If a subject has been without food for 12 hours or more and is drawing upon body material to the extent of 15 per cent of the total energy in the form of protein and the other 85 per cent is apportioned between carbohydrate and fat, presumably in the proportion of 45 per cent of carbohydrate and 40 per cent of fat, the respiratory quotient will be approximately 0.85. When carbohydrate is ingested there is immediately a great rise in the respiratory quotient and an increase in the production of carbon dioxide. It may be argued, then, in common with the old conception of von Hoesslin,[2] that a fat-carbohydrate-protein combustion is replaced by an exclusively protein-carbohydrate combustion, without altering in any way the total amount of energy transformed. This is one possibility.

Another possibility is that there may be a transformation of carbohydrate into fat. By this process, which has been definitely proved in several laboratories in a number of ways, there may be a formation of

[1]Probably no research on the influence of the ingestion of pure carbohydrate has been more accurately and carefully carried out than that of Johansson at Stockholm (see pp. 34 and 35), which was supplemented by the subsequent experiments of Johansson's former assistant, Gigon (see p. 38). While Rubner's criticism (Die Gesetze des Energieverbrauchs bei der Ernährung, 1902, p. 216) of Johansson's method of computing the carbon-dioxide production of a single individual in half-hour periods seems justified when we consider that the volume of air in the chamber was 100,000 liters, nevertheless personal visits to Stockholm have convinced us that the remarkable Sondén gas-analysis apparatus used by Johansson permits measurements of carbon dioxide with a sufficient degree of accuracy to justify recording values for half-hour periods with this chamber, if not, indeed, for 15-minute periods.

[2]von Hoesslin, Arch. f. path. Anat. u. Physiol., 1882, **89**, p. 341.

fat and a splitting off of carbohydrate when large amounts of carbohydrate are ingested, with a so-called "atypical" carbon-dioxide production, unaccompanied by an increase in the oxygen consumption. In other words, this process is entirely aside from the katabolic processes in the body and does not affect the total katabolism appreciably, though there is a slight energy output incidental to the transformation.

Finally, there may be an actual increase in the total katabolism, which would of itself result in an increased carbon-dioxide production. This increase in the katabolism may be caused by an increased tonus and an increased activity in the digestive tract due to the stimulating effect of the absorbed food materials upon the body cells. It is thus clear that these three processes, which may take place simultaneously in varying degrees of intensity, greatly complicate the interpretation of results based only upon the carbon-dioxide increment.

The experiments in this research which were designed to study the influence of the ingestion of carbohydrates were planned to measure not only a prolonged effect but particularly to show the maximum carbon-dioxide production and oxygen consumption which might appear early in the observations. In the calorimeter experiments measurements were also made of the heat production. For the respiration experiments the heat production was calculated from the results obtained for the gaseous exchange. A number of carbohydrate food materials were used, including not only pure carbohydrates, such as cane sugar, dextrose, levulose, and milk sugar, but also those of a mixed nature, like bananas and popcorn. As in the series of experiments already discussed, the data were secured with the respiration calorimeter at Wesleyan University, Middletown, and with the chair calorimeter and two forms of respiration apparatus at the Nutrition Laboratory, Boston.

CALORIMETER EXPERIMENTS.

The agreement between the results obtained by direct and indirect calorimetry in the calorimeter experiments was, in many instances, extremely unsatisfactory, so much so that for a long time we were disposed to question the value of our calorimeter measurements, particularly those with the Boston calorimeters. Subsequent experimentation has shown, however, that direct and indirect calorimetry may not necessarily agree under the abnormal conditions previously outlined which obtain when excessive amounts of carbohydrates are ingested.

To secure a satisfactory agreement between direct and indirect calorimetry is a problem that has received a great deal of attention ever since the earliest days of direct measurements of the heat output of man. The attempt was made in all of our experiments to determine

the heat output directly with as high a degree of accuracy as possible. The respiration calorimeter at Middletown was designed primarily for 24-hour periods. On this basis the agreement between direct and indirect calorimetry has almost invariably proved satisfactory, especially after the apparatus was modified to permit the direct measurement of the oxygen consumption. Previous to the beginning of this research on the influence of food upon the metabolism, no attempt was made to compare direct and indirect calorimetry in periods shorter than 24 hours. When such an attempt was made, it was found that at least with the Middletown calorimeter, which had an air content of approximately 5,000 liters, great difficulty was experienced in the measurement of the residual air and particularly of the residual oxygen, and the possibility of experimental error was thus increased as the periods were decreased in length. Direct measurements of the heat production are also complicated by the difficulty in obtaining accurate measurements of the rectal temperature. Furthermore, the ingestion of large masses of food at a temperature above or below that of the body increases the difficulty, as the length of time required to bring the ingested food and the stomach wall to the temperature of the body is a matter of considerable speculation. Still, the general coincidence of the results obtained with both direct and indirect calorimetry lends credence to any deduction drawn from either. It should be said, further, that the researches conducted under the skillful guidance of Dr. E. F. Du Bois, at the Russell Sage Institute of Pathology in New York, have definitely demonstrated the fact that accurate comparisons of the direct and indirect calorimetry can be secured, even in periods as short as one hour.

Such values for the heat production as were obtained in this research by the indirect method were not computed with the idea of establishing a comparison between the direct and indirect heat values, but simply to obtain a general picture of the course of the metabolism after the ingestion of food. If both the direct and the indirect calorimetry show an increment in the metabolism, there is every reason to believe that such an increment actually took place. While the results obtained with the two methods by no means always agree closely, they yet supply a rough confirmation of each other. As a rule, the tabulated values for the heat production in the calorimeter experiments are those obtained by direct measurement. In one case both sets of figures are given for illustration (see table 101, page 179). Unless otherwise stated, the values for the heat measurements are for the heat actually produced—that is, the measured heat elimination corrected, in accordance with the usage of this laboratory,[1] for changes in body-weight and body-temperature.

[1]Benedict and Joslin, Carnegie Inst. Wash. Pub. No. 136, 1910, p. 20.

Since it is the custom of many writers to compute the non-protein respiratory quotient and determine the non-protein metabolism in experiments of this kind, values for the nitrogen excretion in the urine have been given whenever obtainable, but with no idea of indicating the influence of the ingested food. Although basal values for nitrogen have been included in the tables whenever available, no effort was made to obtain such data for our experiments. In this we find ourselves at variance with Gigon, who assumed that the basal value for nitrogen was constant. It should be emphasized, however, that this research was not planned to study the influence upon the protein katabolism of the ingestion of the various foods studied. The non-protein respiratory quotient is not of special significance in this research and it is deemed unwise to expand the data by including it, especially as it may be computed from the values for the nitrogen excretion as follows:

From the computations of Zuntz it is assumed, for the period in which the non-protein quotient is desired, that for each gram of nitrogen determined in the urine 5.91 liters of oxygen are absorbed and 4.75 liters of carbon dioxide are produced. The values obtained by multiplying these amounts of oxygen and carbon dioxide by the grams of nitrogen are considered to represent the carbon dioxide produced and oxygen consumed in the disintegration of the protein. Since the total oxygen consumption and carbon-dioxide production are determined, the subtraction of the amounts resulting from the katabolism of protein gives the liters of oxygen absorbed and carbon dioxide produced in the katabolism of fat and carbohydrate; the quotient from the division of the amounts so obtained, $\frac{CO_2}{O_2}$, will thus be the non-protein respiratory quotient.

If it is further desired to compute the heat produced by the katabolism of body material, the grams of nitrogen in the urine multiplied by 26.51 calories[1] will give the heat production resulting from the oxidation of protein. By employing the calorific value of oxygen found in the table of Zuntz[2] for the non-protein quotient obtained in the above calculation, the heat that should result from the katabolism of the fat and carbohydrate is obtained. The sum of these computed values for protein and for fat and carbohydrate constitutes the heat produced (computed) for the period under observation.

In discussing the results of the experiments with carbohydrates, the experiments made with the Middletown and Boston calorimeters will first be considered and subsequently those made with the respiration apparatus in Boston. Except in one instance, the experiments in Middletown were carried out in 2-hour periods; in the Boston experiments the periods were only an hour in length, and the basal metabolism was usually determined on the same day.

[1]Loewy, Oppenheimer's Handbuch der Biochemie, 1911, 4 (1), p. 279.
[2]Zuntz and Schumburg, Physiologie des Marsches, 1901, p. 361.

STATISTICS OF CALORIMETER EXPERIMENTS.

The results of all of the calorimeter experiments with carbohydrates are given in tables 101 to 122. Statistical data regarding these experiments, not included in the tables or the discussion, are as follows:

A. H. M., 8h52m a. m. to 4h52m p. m., April 1, 1907. 65.2 kilograms.—Urinated 7h35m a. m. and 12h58m p. m.; drank water (28 grams) at 1h10m p. m. Subject sat quietly most of experimental period, reading much of time. Slight nausea from sugar half hour after taking. Body-temperature: 36.86°, 36.84°, 36.84°, 36.85°, 36.93° C. Pulse rate, 55; respiration rate, 17.

A. W. W., 8h12m a. m. to 12h12m p. m., May 28, 1907. 56.6 kilograms.—Urinated at 7h10m a. m. and at end of each period; drank water at beginning of each period (total amount, 501 grams). Quiet throughout experiment; fell asleep for a few minutes in third period; read most of time. Body-temperature: 36.36°, 36.39°, 36.47°, 36.53°, 36.57° C. Pulse rate, 58; no records of respiration rate.

F. M. M., 9h30m a. m. to 4h30m p. m., January 31, 1910. 61.6 kilograms. 2 basal periods.—But little activity aside from telephoning at least once in each period and urinating at beginning of first period after taking sugar. In fourth period after sugar, fell asleep several times and was asleep much of period; also fell asleep during last period, but was told to stay awake and slept but little afterwards. Drank 18 grams water after taking sugar and lemon solution.

F. M. M., 8h51m a. m. to 2h51m p. m., February 2, 1910. 61.7 kilograms. (2 basal periods).—Urinated 7h40m a. m. and 3 p. m. During basal periods somewhat restless. After sucrose, drank 29 c.c. water; somewhat restless at times in following periods; complained of headache and did not feel very well. Basal periods: pulse rate, 65; respiration rate, 14. After sucrose: pulse rate, 62; respiration rate, 14.

Dr. R., 9h03m a. m. to 5h03m p. m., February 21, 1907. 50.3 kilograms.—Urinated at 7h30m a. m. and in every period but first; drank water at beginning of each period (total amount, 442 grams). Quiet throughout experiment, reading most of time. Found it difficult to eat all the food. Could not breathe easily in last two periods, possibly due to a cold. Pulse rate, 86; respiration rate, 17.

A. H. M., 8h39m a. m. to 4h39m p. m., March 28, 1907. 65 kilograms.—Enema at 7h15m a. m.; urinated at 6 a. m. and 12h48m p. m. Unable to eat as large an amount of the food as had been provided without danger of nausea. Drank water with food (144 grams); also in second and third periods (181 grams). Comparatively quiet, reading much of the time. Body-temperature: 36.93°, 37.09°, 36.92°, 36.90°, 37.09° C. Pulse rate, 63; respiration rate, 19.

A. L. L., 8h18m a. m. to 4h18m p. m., May 13, 1907. 73.1 kilograms.—Urinated 6 a. m., 10 24m a. m. Drank water at beginning of first period (144 grams) and again at beginning of second period (117 grams). Very quiet throughout experiment, reading nearly all of time; dull headache during a part of experiment, which increased towards end, especially in last hour or two. Body-temperature: 36.85°, 36.80°, 36.82°, 36.67°, 36.83° C. Pulse rate, 63; respiration rate, 19.

E. H. B., 8h24m a. m. to 4h24m p. m., May 14, 1907. 72.9 kilograms.—Urinated at 7h15m a. m. Drank water about 8h32m a. m., also at beginning of third period (total amount, 225 grams). Quiet throughout experiment, reading most of time; slight headache after eating food. Body-temperature: 37.01°, 37.11°, 37.10°, 36.69°, 36.89° C. Pulse rate, 59; respiration rate, 20.

J. J. C., 9h07m a. m. to 3h07m p. m., March 4, 1910. 65.0 kilograms. 2. basal periods.—Urinated 7h20m, 9h15m, 10h15m a. m., 1h15m, 2h15m, 3h18m p. m. Basal periods: pulse rate, 64; respiration rate, 20. After food: pulse rate, 63; respiration rate, 19.

A. L. L., 8h40m a. m. to 4h40m p. m., March 30, 1906. 68 kilograms.—Urinated 7h15m a. m. and 4h55m p. m. Very quiet throughout experiment, reading most of time; appeared to doze twice, being awakened in third period. Body-temperature: 36.61°, 36.69°, 36.65°, 36.51°, 36.44° C. Pulse rate, 65; respiration rate, 19.

H. R. D., 8h45m a. m. to 4h45m p. m., March 31, 1906. 59.3 kilograms.—Urinated 7h25m a. m. (after enema), 12h45m p. m., 4h45m p. m., 7h05m p. m. Sat quietly reading about half of time and writing approximately 1½ hours. Body-temperature: 36.64°, 36.92°, 36.90°, 36.86°, 36.59° C. Pulse rate, 78; respiration rate, 20.

A. H. M., 8h57m a. m. to 4h57m p. m., April 2, 1906. 67.5 kilograms.—Urinated 6h45m a. m., 1 p. m., 7h10m p. m.; took enema before entering calorimeter chamber; slight desire to defecate. Body-temperature: 36.51°, 36.76°, 36.51°, 36.46°, 36.32°, 36.05° C. Pulse rate, 65; respiration rate, 20.

A. L. L., 9 a. m. to 9 p. m., April 19, 1906. 67.6 kilograms.—Urinated 7h20m a. m.; sat quietly reading during experiment except when urinating and telephoning at beginning of each period; near end of last period, asleep; very hungry at night. Body-temperature: 36.86°, 36.84°, 36.73°, 36.67°, 36.61°, 36.65°, 36.15° C. Pulse rate, 64; respiration rate, 18.

H. R. D., 8h10m a. m. to 6h10m p. m., April 21, 1906. 59.4 kilograms.—Urinated at beginning of each period; otherwise very quiet, reading about two hours and rest of time idle. Body-temperature: 36.97°, 36.93°, 37.01°, 36.88°, 36.84°, 36.85° C. Pulse rate, 78; respiration rate, 19.

J. J. C., 10h56m a. m. to 5h56m p. m., April 7, 1909. 67.6 kilograms. 3 basal periods.—Urinated 6h45m, 11h06m a. m., 2h06m, 6h03m p. m. Fell asleep several times during experiment; wakened from sound sleep at 12h58m p. m. and 3h56m p. m. Basal periods: pulse rate, 60; respiration rate, 18. Food periods: pulse rate, 71; respiration rate, 20.

F. M. M., 10h24m a. m. to 4h24m p. m., April 8, 1909. 59.4 kilograms. 3 basal periods.—Urinated and defecated at 9h05m a. m., urinated at 1h32m p. m. and immediately after experiment. At end of third basal period, asleep for about 20 minutes, waking up just before end of period, then unusually active. Considerable telephoning at beginning of periods in connection with weighings. Restless during last food period. Basal periods: pulse-rate, 52; respiration rate, 15. After food: pulse rate, 57; respiration rate, 17.

F. M. M., 9h38m a. m. to 3h38m p. m., February 8, 1910. 61.8 kilograms. 2 basal periods.—Urinated 7 a. m., 11h40m a. m., 3h50m p. m. Drank water 9h45m, 10h58m, 11h55m a. m., 12h55m p. m. (230 grams in all). At end of first basal period and beginning of second, restless. During last food period, asleep part of time but quite restless whenever awake; was required to press push button to ring bell outside, thus indicating that he was awake. Basal periods: pulse rate, 61; respiration rate, 13. Food periods: pulse rate, 59; respiration rate, 14.

Dr. H., 9h24m a. m. to 2h24m p. m., February 14, 1910. 66.6 kilograms. 2 basal periods.—Urinated 8, 9h28m, 11h32m a. m., 1h30m, 2h30m p. m. Drank water 11h36m a. m. (135 grams). Basal periods: pulse rate, 58; respiration rate, 13. Food periods: pulse rate, 61; respiration rate, 14.

Dr. H., 9h31m a. m. to 3h31m p. m., February 17, 1910. 66.0 kilograms. 2 basal periods.—Urinated 8, 9h40m, 11h36m a. m., 2h50m, 3h31m p. m. Drank

water at 11^h45^m a. m. (112 grams). Basal periods: pulse rate, 59; respiration rate, 12. Food periods: pulse rate, 62; respiration rate, 13.

H. B. W., 9^h14^m a. m. to 5^h14^m p. m., April 9, 1907. 62.6 kilograms.—Defecated before coming to laboratory; urinated at 8^h20^m a. m. Very quiet nearly all of experimental period, most movement being in second and third periods. Head ached last period, probably due to reading steadily. Body-temperature: 36.80°, 36.79°, 36.85°, 36.93°, 36.97° C. Pulse rate, 59; respiration rate, 18.

A. H. M., 9^h23^m a. m. to 5^h23^m p. m., April 10, 1907. 66.6 kilograms.—Urinated 7^h30^m, 11^h32^m a. m., 3^h30^m p. m.; attempted to urinate at 1^h30^m p. m. Somewhat restless throughout experiment but did not rise from chair; reading much of time; seldom motionless for more than half minute at a time; difficult to get records of respiration and pulse rates; in last period more quiet; slight headache in afternoon. Body-temperature: 36.76°, 36.70°, 36.84°, 36.80°, 36.78° C. Pulse rate, 63; respiration rate, 19.

A. L. L., 8^h30^m a. m. to 4^h30^m p. m., May 27, 1907. 74.7 kilograms.—Urinated 7^h05^m a m.; very quiet during experiment; fell asleep in second period and had to be awakened; also slept for short time in last period. Body-temperature: 36.62°, 36.28°, 36.22°, 36.12°, 36.20° C. Pulse rate, 61; respiration rate, 18.

DISCUSSION OF CALORIMETER EXPERIMENTS.

SUCROSE.

Four experiments were made with sucrose, one each with A. H. M. and A. W. W. with the respiration calorimeter in Middletown, and two with F. M. M. with the chair calorimeter in Boston.

A. H. M., April 1, 1907.—This experiment was the first in this research in which a pure carbohydrate was ingested. The amount taken was 191 grams, with a total energy value of 756 calories. An inspection of table 101 shows a considerable increase in the carbon-dioxide production after food which persisted during the first three periods but does not appear in the last period. The oxygen consumption shows a marked increase in the first period, with a return to the basal value immediately thereafter. High respiratory quotients, which usually follow the ingestion of sugar, were found in the first two periods with a quotient approximating basal in the last period. The striking abnormality in the values for this experiment is the fact that the oxygen increment appears only in the first period, while the increase in the heat production continues throughout all four periods. An explanation of this on any other ground than that of unrecognized faulty technique is at present very difficult.

As there were certain discrepancies in the measurements of the rectal temperature which led us to consider the records doubtful, it seemed desirable to compare the direct measurements of the heat output with the values calculated from the gaseous metabolism. For this particular experiment, therefore, the values obtained by indirect calorimetry are also recorded, although it should again be emphasized that the values for the indirect heat are not given for the specific purpose

of noting the increment above the basal value but simply to obtain the general trend of the metabolism from period to period for comparison with the direct measurements of the heat production. Aside from the first period, in which the computed heat is 16 calories higher than the determined, all the values found by direct calorimetry are higher than those computed. The average for the entire experiment shows a discrepancy between the values obtained by the two methods of approximately 6 per cent. While this discrepancy appears very large in the light of the recent exact work of Du Bois, it should be remembered that this particular calorimeter had a very large volume and was primarily designed for 24-hour experiments. The lack of agreement between the direct and indirect calorimetry in these short periods is, therefore, not so incongruous as at first sight appears.

It should be noted that for computing the increment in the heat production by the indirect method the basal value computed by indirect calorimetry (152 calories) was used in place of the basal value of 164 calories given at the head of table 101, which was obtained by direct calorimetry. The non-protein respiratory quotients are not here tabulated, but have all been computed and used in obtaining the heat production by the indirect method. In general they are two to three points higher than the respiratory quotients recorded, as is the case in practically all of the experiments in this report.

TABLE 101.—*A. H. M., April 1, 1907. Sitting.* (2-hour periods.)

Sucrose:[1]
Amount, 191 grams; energy, 756 cals.; from carbohydrates, 100 p. ct.
Basal values (March 6 and 9, 1907): CO_2, 51 grams; O_2, 46 grams; heat, 164 cals.

Time elapsed since subject finished eating.[1]	Nitrogen in urine per 2 hours.	Carbon dioxide.		Oxygen.		Heat.			Respiratory quotient.
		Total.	Increase.	Total.	Increase.	Determined.		Computed.	
						Total.	Increase.		
	gram.	*grams.*	*grams.*	*grams.*	*grams.*	*cals.*	*cals.*	*cals.*	
¼ to 2¼ hours	0.95[2]	79	28	60	14	192	28	208	0.95
2¼ to 4¼ hours	.95[2]	60	9	46	0	185	21	158	.95
4¼ to 6¼ hours	.81	56	5	47	1	174	10	159	.86
6¼ to 8¼ hours	.81	51	0	45	−1	173	9	152	.82
Total....	....	246	42	198	14	724	68	677	....

[1]Subject took sugar, together with 119 grams water, in 25 minutes.
[2]Sample included amount for about an hour preceding the taking of sugar.

A. W. W., May 28, 1907.—A much smaller amount of sugar (80 grams, with an energy value of 317 calories) was taken in this experiment as compared with that eaten in the preceding experiment. The periods were but an hour in length instead of 2 hours, as in the experiment with A. H. M.; the wisdom of attempting to shorten the measurements of the metabolism to 1 hour is, however, questionable. The

results obtained are given in table 102. Practically the entire increment in the carbon-dioxide production was found in the first hour. The oxygen consumption showed almost no increase after the ingestion of the carbohydrate; in fact, there was a total decrease of 5 grams. The slight increase in the heat production in the first two periods was in part compensated by an actual loss in the subsequent periods. It would appear probable from these data that the basal value selected for this experiment should not properly be used, especially in view of the fact that it is an average of two values obtained some two months before the experiment with sugar was made, *i. e.*, on March 15 and 21, 1907. The specially significant points in connection with this experiment are that the carbon-dioxide production increased in the first hour and that nearly all of the respiratory quotients were somewhat high. The fact that two of these quotients were as high as 1.19 and 1.10 throws considerable doubt upon the accuracy of the measurements of the oxygen consumption.

The values for this experiment are presented chiefly as an illustration of the difficulty of studying problems of this kind when small amounts of ingested material are used, an attempt is made to lower the period of measurement to one hour with so large a calorimeter as that used in Middletown, and an apparently defective basal value is selected which was obtained several months previous to the experiment.

TABLE 102.—*A. W. W., May 28, 1907. Sitting.* (1-hour periods.)

Sucrose:
Amount, 80 grams; energy, 317 cals.; from carbohydrates, 100 p. ct.
Basal values (March 15 and 21, 1907): CO_2, 25 grams; O_2, 21 grams; heat, 78 cals.

Time elapsed since subject finished eating.	Nitrogen in urine per hour.	Carbon dioxide.		Oxygen.		Heat.		Respiratory quotient.
		Total.	Increase.	Total.	Increase.	Total.	Increase.	
	gram.	*grams.*	*grams.*	*grams.*	*grams.*	*cals.*	*cals.*	
¼ to 1¼ hours	0.31	38	13	23	2	84	6	1.19
1¼ to 2¼ hours	.31	26	1	19	−2	83	5	1.02
2¼ to 3¼ hours	.27	21	−4	19	−2	74	−4	.80
3¼ to 4¼ hours	.27	27	2	18	−3	77	−1	1.10
Total....	...	112	12	79	−5	318	6	....

F. M. M., January 31, 1910.—In the first Boston experiment the subject took 100 grams of sucrose and the juice of one lemon with a total energy value of 408 calories. The data given in table 103 for this experiment show an increase in the carbon-dioxide production for the first three periods and a slight increase in the oxygen consumption with measurable increase in heat production. Thus all three factors

indicate an increment in metabolism as a result of the ingestion of sugar. As a rule, the respiratory quotients were characteristically high. The basal value used for this experiment was an average of four values, one obtained on the morning of the same day and the others determined at intervals in the following three weeks. The total increments of 18 grams of carbon dioxide, 4.5 grams of oxygen, and 19 calories of heat over the basal value in the course of 5 hours show a definite effect on the metabolism as a result of the ingestion of sugar.

TABLE 103.—*F. M. M., January 31, 1910. Sitting.* (1-hour periods.)

Sucrose:
Amounts, 100 grams sucrose, and juice of one lemon; energy, 408 cals.; from carbohydrates, 100 p. ct. Nitrogen in urine, 0.53 gram per hour.
Basal values (January 31 to February 19, 1910): CO_2, 26.5 grams; O_2, 23.0 grams; heat,[1] 80 cals. On January 31, 1910, respiratory quotient, 0.86; nitrogen in urine, 0.54 gram per hour.

Time elapsed since subject finished eating.	Carbon dioxide.		Oxygen.		Heat.[1]		Respiratory quotient.
	Total.	Increase.	Total.	Increase.	Total.	Increase.	
	grams.	*grams.*	*grams.*	*grams.*	*cals.*	*cals.*	
0 to 1 hours[2]	32.5	6.0	25.0	2.0	89	9	0.94
1 to 2 hours	35.0	8.5	25.5	2.5	83	3	.99
2 to 3 hours	31.0	4.5	26.0	3.0	88	8	.87
3 to 4 hours	25.5	−1.0	21.0	−2.0	80	0	.89
4 to 5 hours	26.5	0.0	22.0	−1.0	79	−1	.87
Total	150.5	18.0	119.5	4.5	419	19	....

[1]Heat eliminated corrected for change in body-weight, but not for change in body-temperature
[2]Subject finished drinking solution (373 grams) 12 minutes after the beginning of this period

TABLE 104.—*F. M. M., February 2, 1910. Sitting.* (1-hour periods.)

Sucrose:
Amounts, 100 grams sucrose and juice of one lemon; energy, 408 cals.; from carbohydrates, 100 p. ct. Nitrogen in urine, 0.60 gram per hour.[1]
Basal values (February 2, 1910): CO_2, 27.5 grams; O_2, 23.5 grams; heat,[2] 78 cals.; respiratory quotient, 0.86.

Time elapsed since subject finished eating.	Carbon dioxide.		Oxygen.		Heat.[2]		Respiratory quotient.
	Total.	Increase.	Total.	Increase.	Total.	Increase.	
	grams.	*grams.*	*grams.*	*grams.*	*cals*	*cals.*	
0 to 1 hours[3]	33.5	6.0	26.5	3.0	85	7	0.91
1 to 2 hours	34.5	7.0	25.5	2.0	83	5	.98
2 to 3 hours	29.0	1.5	24.5	1.0	82	4	.86
3 to 4 hours	27.5	0.0	22.5	−1.0	78	0	.89
Total	124.5	14.5	99.0	5.0	328	16	....

[1]Sample included amount for 3¼ hours without food preceding experiment.
[2]Heat eliminated corrected for change in body-weight, but not for change in body-temperature.
[3]Subject drank solution (386 grams) at beginning of this period.

F. M. M., February 2, 1910.—In the second sucrose experiment with this subject the same amounts of sugar and lemon juice were taken as in the first experiment. The basal value was determined immediately prior to the values after food. The data given in table 104 show an increment in the carbon-dioxide production, a slight increment in the oxygen consumption, and a perceptible increment in the heat production in the first three periods. High respiratory quotients are also recorded.

MALTOSE-DEXTROSE MIXTURE.

The only pure carbohydrate used in the calorimeter experiments was sucrose. The fear of digestive disturbances, which subsequent experimenting proved groundless, led us to consider the possibility of some other type of sugar and a patent preparation was therefore used. The results of four analyses of this material show, on the average, about 39 per cent of maltose, 27 per cent of dextrose, and 34 per cent of water. Four experiments were made with this material in Middletown, and one with J. J. C. in Boston.

Dr. R., February 21, 1907.—In the first experiment with this food material 458 grams were eaten, with a total energy of 1,382 calories. From the analysis it can be seen that a considerable part of the material was water and that the dry matter was practically pure carbohydrate.

This subject had previously used the maltose-dextrose mixture in his daily diet and was thus accustomed to it. In all of the four 2-hour periods a striking rise in the carbon-dioxide production was noted. (See table 105.) Singularly the oxygen consumption was almost invariably below the basal requirement, which, in this instance, was determined on the preceding day. This deficiency we are unable to explain. The heat production was increased during all of the four

TABLE 105.—*Dr. R., February 21, 1907. Sitting.* (2-hour periods.)

Maltose-dextrose mixture:
Amount, 458 grams; energy, 1,382 cals.; from carbohydrates, 100 p. ct.
Basal values (February 20, 1907): CO_2, 48 grams; O_2, 45 grams; heat,[1] 146 cals. Nitrogen in urine, 0.55 gram per 2 hours (February 21, 1907).

Time elapsed since subject finished eating	Nitrogen in urine per 2 hours.	Carbon dioxide.		Oxygen.		Heat.[1]		Respiratory quotient.
		Total.	Increase.	Total.	Increase.	Total.	Increase.	
	gram.	*grams.*	*grams.*	*grams.*	*grams.*	*cals.*	*cals.*	
¼ to 2¼ hours.	0.78[2]	62	14	38	−7	158	12	1.19
2¼ to 4¼ hours.	.59	63	15	46	1	163	17	.98
4¼ to 6¼ hours.	.58	64	16	43	−2	169	23	1.09
6¼ to 8¼ hours.	.75	66	18	42	−3	168	22	1.16
Total....	....	255	63	169	−11	658	74	....

[1]Heat eliminated corrected for change in body-weight, but not for change in body-temperature.
[2]Sample included amount for about 1¼ hours preceding taking of maltose-dextrose mixture.

periods, this being in conformity with the increase in the carbon-dioxide production. The abnormal values for the oxygen consumption in part explain the high respiratory quotients, which are, in two instances, 1.19 and 1.16. In all probability there was an error in the measurement of the oxygen consumption.

A. H. M., March 28, 1907.—The results obtained after the subject had taken 307 grams of the maltose-dextrose mixture, with an energy value of 927 calories, are given in table 106. During the four 2-hour periods there was the usual noticeable increase in the carbon-dioxide production, a total increase of 15 grams in the oxygen consumption, and in every period an increase in the heat production, although the increase in the latter factor was but slight in the fourth period. The general picture points towards a distinct increase in the metabolism after the ingestion of the maltose-dextrose mixture. The respiratory quotients were high, as would be expected; the last value is undoubtedly erroneous.

TABLE 106.—*A. H. M., March 28, 1907. Sitting.* (2-hour periods.)

Maltose-dextrose mixture:[1]
Amount, 307 grams; energy, 927 cals.; from carbohydrates, 100 p. ct.
Basal values (March 6 and 9, 1907): CO_2, 51 grams; O_2, 46 grams; heat, 164 cals.

Time elapsed since subject finished eating.[1]	Nitrogen in urine per 2 hours.	Carbon dioxide.		Oxygen.		Heat.[2]		Respiratory quotient.
		Total.	Increase.	Total.	Increase.	Total.	Increase.	
	grams.	*grams.*	*grams.*	*grams.*	*grams.*	*cals.*	*cals.*	
½ to 2½ hours.	1.11[3]	70	19	52	6	210	46	0.98
2½ to 4½ hours.	1.11[3]	70	19	48	2	190	26	1.07
4½ to 6½ hours.	.99	55	4	44	−2	183	19	.92
6½ to 8½ hours.	.99	57	6	55	9	167	3	.75
Total....	....	252	48	199	15	750	94	....

[1]Subject took maltose-dextrose mixture, together with 144 grams water, in 17 minutes.
[2]Heat eliminated corrected for change in body-weight, but not for change in body-temperature.
[3]Sample included amount for about 2 hours preceding taking of maltose-dextrose mixture.

A. L. L., May 13, 1907.—The subject took 299 grams of the maltose-dextrose mixture with an energy value of 902 calories. According to the data in table 107, the carbon-dioxide production increased considerably in the first three periods, but practically no increment was found in the oxygen consumption. A distinct increase in the heat production may be noted in the first two periods; the values in the last two periods were irregular, but on the average there was clearly an increment in the last 4 hours. The respiratory quotients were extraordinarily high, this being due in part to the increment in the carbon-dioxide production and in part to the absence of increment in the oxygen consumption. The values for the oxygen consumption, which show a definite decrease in the last three periods, are obviously wrong.

TABLE 107.—*A. L. L., May 13, 1907. Sitting.* (2-hour periods.)

Maltose-dextrose mixture:
Amount, 299 grams; energy, 902 cals.; from carbohydrates, 100 p. ct.
Basal values (May 4, 1907): CO_2, 51 grams; O_2, 43 grams; heat,[1] 158 cals.

Time elapsed since subject finished eating.	Nitrogen in urine per 2 hours.	Carbon dioxide.		Oxygen.		Heat.		Respiratory quotient.
		Total.	Increase.	Total.	Increase.	Total.	Increase.	
	gram.	*grams.*	*grams.*	*grams.*	*grams.*	*cals.*	*cals.*	
¼ to 2¼ hours.	0.70[2]	69	18	44	1	178	20	1.15
2¼ to 4¼ hours.	.65	67	16	42	−1	174	16	1.17
4¼ to 6¼ hours.	.65	60	9	37	−6	155	−3	1.18
6¼ to 8¼ hours.	.65	52	1	42	−1	165	7	.90
Total....	....	248	44	165	−7	672	40	....

[1]Heat eliminated corrected for change in body-weight, but not for change in body-temperature.
[2]Sample included amount for about 2 hours preceding the taking of maltose-dextrose mixture.

E. H. B., May 14, 1907.—The subject was given 431 grams of the maltose-dextrose mixture with an energy value of 1,301 calories. An examination of table 108 shows the usual striking increase in the carbon-dioxide production throughout the entire experiment. There was also an increase in the oxygen consumption in the first period, with practically no change in the subsequent periods, and an increase in the heat production in the first three periods with a slight loss in the last period. The evidence clearly points towards a distinct increase in metabolism as a result of the ingestion of carbohydrate.

TABLE 108.—*E. H. B., May 14, 1907. Sitting.* (2-hour periods.)

Maltose-dextrose mixture:
Amount, 431 grams; energy, 1,301 cals.; from carbohydrates, 100 p. ct. Nitrogen in urine 1.20 grams per 2 hours.
Basal values (March 7 and 13, 1907): CO_2, 58 grams; O_2, 48 grams; heat, 179 cals.

Time elapsed since subject finished eating.[1]	Carbon dioxide.		Oxygen.		Heat.[2]		Respiratory quotient.
	Total.	Increase.	Total.	Increase.	Total.	Increase.	
	grams.	*grams.*	*grams.*	*grams.*	*cals.*	*cals.*	
0 to 2 hours.....	74	16	54	6	199	20	0.99
2 to 4 hours.....	73	15	47	−1	189	10	1.13
4 to 6 hours.....	73	15	50	2	191	12	1.05
6 to 8 hours.....	65	7	46	−2	176	−3	1.04
Total.....	285	53	197	5	755	39	....

[1]Subject took maltose-dextrose mixture in 30 minutes.
[2]Heat eliminated corrected for change in body-weight, but not for change in body-temperature.

J. J. C., March 4, 1910.—Following the ingestion of 145 grams of maltose-dextrose mixture and the juice of one lemon, with a total energy value of 449 calories, positive increases were found for the

carbon-dioxide production in all of the periods and an increment in both the oxygen consumption and the heat production in the first three periods. (See table 109.) With this subject it is clearly evident from the general picture that this amount of maltose-dextrose mixture produced a positive increase above the basal metabolism. Although the respiratory quotient in the first two periods was unusually low, it rose until in the fourth period it was slightly over 1.

TABLE 109.—*J. J. C., March 4, 1910. Sitting.* (1-hour periods.)

Maltose-dextrose mixture:[1]
Amounts, 145 grams maltose-dextrose mixture, juice of one lemon; energy, 449 cals.; from carbohydrates, 100 p. ct.
Basal values (March 4, 1910): CO_2, 26.0 grams; O_2, 22.0 grams; heat (computed), 74 cals.; respiratory quotient, 0.86. Nitrogen in urine, 0.47 gram per hour.

Time elapsed since subject finished eating.[1]	Nitrogen in urine per hour.	Carbon dioxide.		Oxygen.		Heat (computed).		Respiratory quotient.
		Total.	Increase.	Total.	Increase.	Total.	Increase.	
	gram.	*grams.*	*grams.*	*grams.*	*grams.*	*cals.*	*cals.*	
0 to 1 hours...	0.46[2]	29.0	3.0	24.5	2.5	82	8	0.86
1 to 2 hours...	.46[2]	33.0	7.0	28.0	6.0	95	21	.86
2 to 3 hours...	.44	33.0	7.0	25.5	3.5	88	14	.93
3 to 4 hours...	.43	29.0	3.0	20.5	−1.5	72	−2	1.01
Total....	...	124.0	20.0	98.5	10.5	337	41	....

[1]Subject finished drinking solution (333 grams) in 17 minutes after the beginning of this period. The drinking occupied 4 minutes.
[2]Sample included amount for about 1 hour preceding the taking of maltose-dextrose mixture.

BANANAS AND SUGAR.

Bananas and sugar were given in several experiments, as considerable amounts could be consumed and the total energy intake in the form of carbohydrate thus be greatly increased. The results of 7 experiments follow; the experiments with A. L. L., H. R. D., and A. H. M. were made in Middletown, and those with J. J. C. and F. M. M. in Boston.

A. L. L., March 30, 1906 (765 grams bananas and 99 grams sugar, with a total fuel value of 1,109 calories).—A very large increase in the carbon-dioxide production was found in the first period, this being decreased about one-half in the second period. (See table 110.) In the last two periods the amount was essentially the same as the basal value. There was an increase of 17 grams in the oxygen consumption in the first period with practically basal values thereafter. The heat production showed a large increase for the first two periods, but the values were essentially the same as the basal in the last two periods. The respiratory quotients were extraordinarily high and characteristic of those following carbohydrate ingestion. In this experiment, therefore, there was a somewhat closer uniformity between the gaseous metabolism and heat production than in many of the earlier experi-

ments. All of the factors indicate a considerable increase in the actual metabolic processes.

TABLE 110.—*A. L. L., March 30, 1906. Sitting.* (2-hour periods.)

Bananas and sugar:
Amounts, 765 grams bananas, 99 grams sugar; nitrogen, 1.58 grams; total energy, 1,123 cals.
Fuel value: Total, 1,109 cals.; from protein, 3 p. ct.; from fat, 4 p. ct.; from carbohydrates, 93 p. ct.
Nitrogen in urine, 0.73 gram per 2 hours.
Basal values (April 3 and 6, 1906): CO_2, 47 grams; O_2, 43 grams; heat, 145 cals.

Time elapsed since subject finished eating.[1]	Carbon dioxide.		Oxygen.		Heat.		Respiratory quotient.
	Total.	Increase.	Total.	Increase.	Total.	Increase.	
	grams.	*grams.*	*grams.*	*grams.*	*cals.*	*cals.*	
0 to 2 hours	80	33	60	17	195	50	0.97
2 to 4 hours	65	18	42	−1	183	38	1.13
4 to 6 hours	49	2	36	−7	151	6	1.00
6 to 8 hours	50	3	40	−3	139	−6	.90
Total	244	56	178	6	668	88	....

[1]Subject ate food in 31 minutes.

H. R. D., March 31, 1906. (1,173 grams bananas and 103 grams sugar, with a total fuel value of 1,562 calories).—The data given in table 111 show large increases in the carbon-dioxide excretion over the basal value in the first three periods. There was a concordant increase in the oxygen consumption and an increment in the heat production. We thus have here practically the same picture with all three factors of metabolism, indicating an increased metabolism following the ingestion of bananas and sugar.

TABLE 111.—*H. R. D., March 31, 1906. Sitting.* (2-hour periods.)

Bananas and sugar:
Amounts, 1,173 grams bananas, 103 grams sugar; nitrogen, 2.43 grams; total energy, 1,583 cals.
Fuel value: Total, 1,562 cals.; from protein, 4 p. ct.; from fat, 4 p. ct.; from carbohydrates, 92 p. ct.
Nitrogen in urine, 0.78 gram per 2 hours.
Basal values (February 6 to April 20, 1906): CO_2, 47 grams; O_2, 42 grams; heat, 146 cals.

Time elapsed since subject finished eating.[1]	Carbon dioxide.		Oxygen.		Heat.		Respiratory quotient.
	Total.	Increase.	Total.	Increase.	Total.	Increase.	
	grams.	*grams.*	*grams.*	*grams.*	*cals.*	*cals.*	
0 to 2 hours	72	25	54	12	191	45	0.97
2 to 4 hours	69	22	52	10	182	36	.96
4 to 6 hours	65	18	50	8	172	26	.95
6 to 8 hours	55	8	42	0	146	0	.95
Total	261	73	198	30	691	107	....

[1]Subject ate food in 27 minutes.

A. H. M., April 2, 1906 (1,121 grams bananas and 86 grams sugar, with a total fuel value of 1,448 calories).—The values for both the carbon-dioxide excretion and the heat production recorded in table 112 indicate an increase in all of the periods of this experiment; the oxygen consumption also showed an increment in the first three periods. The respiratory quotients were in all cases high, the first quotient being above 1. A fairly uniform picture of increased metabolism was thus shown throughout the entire observation.

TABLE 112.—*A. H. M., April 2, 1906. Sitting.* (2-hour periods.)

Bananas and sugar:
Amounts, 1,121 grams bananas, 86 grams sugar; nitrogen, 2.34 grams; total energy, 1,468 cals.
Fuel value: Total, 1,448 cals.; from protein, 4 p. ct.; from fat, 4 p. ct.; from carbohydrates, 92 p. ct.
Nitrogen in urine, 0.79 gram per 2 hours.[1]
Basal values (February 12 and 14, 1906): CO_2, 45 grams; O_2, 40 grams; heat, 142 cals.

Time elapsed since subject finished eating.[2]	Carbon dioxide.		Oxygen.		Heat.		Respiratory quotient.
	Total.	Increase.	Total.	Increase.	Total.	Increase.	
	grams.	*grams.*	*grams.*	*grams.*	*cals.*	*cals.*	
0 to 2 hours.....	79	34	56	16	182	40	1.03
2 to 4 hours.....	68	23	52	12	167	25	.95
4 to 6 hours.....	65	20	48	8	166	24	.98
6 to 8 hours.....	51	6	39	−1	147	5	.96
Total.....	263	83	195	35	662	94	....

[1]Sample included amount for about $1\frac{3}{4}$ hours preceding the eating of food.
[2]Subject ate food in 27 minutes.

A. L. L., April 19, 1906 (763 grams bananas and 99 grams sugar, with a fuel value of 1,147 calories).—In this second experiment with A. L. L. the amounts of bananas and sugar eaten were almost identical with those taken in the experiment of March 30, 1906, but the observations continued for 12 hours instead of for 8 hours, as in the duplicate experiment. The results are given in table 113. The carbon-dioxide excretion remained above the basal value in all of the six periods, although the increases in the first two periods were the most striking. An increase in oxygen consumption was found in the first and second periods, with slight variations above or below the base-line in the following periods. The increase in heat production was very marked in the first three periods. A striking anomaly is a decrease of 25 calories in the last period, illustrating one of the defects of short-period determinations with this large calorimeter. The general picture with all three factors is a noticeable increase in the metabolism.

The total increases in these duplicate experiments do not give a wholly satisfactory comparison. Thus, in the experiment of March 30 there was an increase in the carbon-dioxide excretion of 56 grams, while

in that of April 19 it was 74 grams. If the 7 grams increment noted in the last two periods of the experiment on April 19 be deducted, the increment for the first four periods would be 67 grams as compared with the 56 grams for the same period of time on March 30. In both experiments the oxygen increment appeared in the first period and was not far from the same in the two experiments. The increase in the heat production was 88 calories in the first experiment and but 72 calories in the second. If, however, the results of the last period of the second experiment be omitted, the increment would be 97 calories, or a little larger than that found in the first experiment. In general the two experiments may be said to be in fair agreement, as both indicate a noticeable rise in heat production following the ingestion of bananas and sugar.

TABLE 113.—*A. L. L., April 19, 1906. Sitting.* (2-hour periods.)

Bananas and sugar:
Amounts, 763 grams bananas, 99 grams sugar; nitrogen, 1.58 grams; total energy, 1,160 cals. Fuel value: Total, 1,147 cals.; from protein, 3 p. ct.; from fat, 4 p. ct.; from carbohydrates, 93 p. ct.

Basal values: (February 7 to April 6, 1906): CO_2, 47 grams; O_2, 42 grams; heat, 148 cals. Nitrogen in urine, 0.71 gram per 2 hours (April 19, 1906).

Time elapsed since subject finished eating.	Nitrogen in urine per 2 hours.	Carbon dioxide.		Oxygen.		Heat.		Respiratory quotient.
		Total.	Increase.	Total.	Increase.	Total.	Increase.	
	gram.	*grams.*	*grams.*	*grams.*	*grams.*	*cals.*	*cals.*	
¼ to 2¼ hours.	0.51	80	33	55	13	194	46	1.06
2¼ to 4¼ hours.	.86	69	22	47	5	181	33	1.07
4¼ to 6¼ hours.	.72	55	8	40	−2	166	18	.99
6¼ to 8¼ hours.	.59	51	4	42	0	147	−1	.89
8¼ to 10¼ hours	.54	51	4	39	−3	149	1	.94
10¼ to 12¼ hours	.47	50	3	45	3	123	−25	.80
Total....	...	356	74	268	16	960	72	....

H. R. D., April 21, 1906 (1,171 grams bananas and 103 grams sugar, with a total fuel value of 1,561 calories).—This was the second experiment with the subject in which bananas and sugar were taken, the amounts being practically the same as those eaten on March 31, 1906. The observations in this experiment, however, continued for 2 hours longer than in the first experiment. The data are given in table 114. There was a noticeable increase in the carbon-dioxide production, even in the fifth period. Increments were also observed for both the oxygen consumption and the heat production. The respiratory quotients were high, but none of them were over 1. If we omit all of the values found for the last period, the results will be comparable with those obtained in the experiment of March 31 and not dissimilar. In the first experiment the increment for carbon-

dioxide production was 73 grams, for oxygen consumption 30 grams, and for heat production 107 calories. In the second experiment the increase in carbon-dioxide excretion for the first four periods was 64 grams, for oxygen consumption 34 grams, and for heat production 116 calories. The nitrogen in the urine per 2 hours was very much greater in this experiment than in the first, averaging 1.23 grams for the first four periods as compared with 0.78 gram in the experiment of March 31.

TABLE 114—*H. R. D., April 21, 1906. Sitting.* (2-hour periods.)

Bananas and sugar:

Amounts, 1,171 grams bananas, 103 grams sugar; nitrogen, 2.10 grams; total energy, 1,580 cals.

Fuel value: Total, 1,561 cals.; from protein, 3 p. ct.; from fat, 4 p. ct.; from carbohydrates, 93 p. ct.

Basal values (February 6 to April 20, 1906): CO_2, 47 grams; O_2, 42 grams; heat, 146 cals. Nitrogen in urine, 0.97 gram per 2 hours (April 21, 1906).

Time elapsed since subject finished eating.[1]	Nitrogen in urine per 2 hours.	Carbon dioxide.		Oxygen.		Heat.		Respiratory quotient.
		Total.	Increase.	Total.	Increase.	Total.	Increase.	
	grams.	*grams.*	*grams.*	*grams.*	*grams.*	*cals.*	*cals.*	
¼ to 2¼ hours.	1.59	62	15	55	13	180	34	0.82
2¼ to 4¼ hours.	1.52	68	21	57	15	186	40	.87
4¼ to 6¼ hours.	1.28	64	17	47	5	170	24	.99
6¼ to 8¼ hours.	.54	58	11	43	1	164	18	.98
8¼ to 10¼ hours.	1.02	52	5	56	14	167	21	.67
Total....	....	304	69	258	48	867	137	....

[1]Subject ate food in 36 minutes.

TABLE 115.—*J. J. C., April 7, 1909. Sitting.* (1-hour periods.)

Bananas and sugar:

Amounts, 648 grams bananas, 77 grams sugar; nitrogen, 1.34 grams; total energy, 974 cals.

Fuel value: Total, 962 cals.; from protein, 4 p. ct.; from fat, 4 p. ct.; from carbohydrates, 92 p. ct.

Nitrogen in urine, 0.40 gram per hour.

Basal values (April 7, 1909): CO_2, 25.5 grams; O_2, 21.5 grams; heat (computed), 72 cals.; respiratory quotient, 0.87. Nitrogen in urine, 0.38 gram per hour.

Time elapsed since subject finished eating.	Carbon dioxide.		Oxygen.		Heat (computed).		Respiratory quotient.
	Total.	Increase.	Total.	Increase.	Total.	Increase.	
	grams.	*grams.*	*grams.*	*grams.*	*cals.*	*cals.*	
0 to 1 hour[1]	33.0	7.5	26.0	4.5	90	18	0.92
1 to 2 hours.....	36.0	10.5	25.5	4.0	89	17	1.02
2 to 3 hours.....	34.5	9.0	26.5	5.0	91	19	.96
3 to 4 hours.....	32.0	6.5	25.5	4.0	87	15	.92
Total.....	135.5	33.5	103.5	17.5	357	69	....

[1]Subject finished eating 28 minutes after the beginning of this period. The eating occupied 20 minutes.

J. J. C., April 7, 1909 (648 grams bananas, 77 grams sugar, with a total fuel value of 962 calories).—The basal value for this experiment was obtained on the same day. The data given in table 115 record a striking increase in carbon-dioxide production for all of the periods, also an increase in oxygen consumption and heat production, the increment of the three factors being reasonably comparable. The respiratory quotients were high, reaching 1.02 in the second period. We have here, therefore, a distinct increase in the metabolism as measured not only by the respiratory exchange but by the heat production.

F. M. M., April 8, 1909 (611 grams bananas, 9 grams sugar, with a total fuel value of 655 calories).—The results obtained in the three 1-hour periods indicate a considerable rise in carbon-dioxide production, oxygen consumption, and heat production, although the increment in the heat production in the last two periods was not very marked. (See table 116.) The respiratory quotients increased from 0.82 to 0.90 as the experiment progressed.

TABLE 116.—*F. M. M., April 8, 1909. Sitting.* (1-hour periods.)

Bananas and sugar:
Amounts, 611 grams bananas, 9 grams sugar; nitrogen, 1.26 grams; total energy, 666 cals.
Fuel value: Total, 655 cals.; from protein, 5 p. ct.; from fat, 5 p. ct.; from carbohydrates, 90 p. ct.
Nitrogen in urine, 0.51 gram per hour.
Basal values (April 8, 1909): CO_2, 23.5 grams; O_2 20.5 grams; heat,[1] 79 cals.; respiratory quotient, 0.82. Nitrogen in urine, 0.39 gram per hour.

Time elapsed since subject finished eating.	Carbon dioxide.		Oxygen.		Heat.[1]		Respiratory quotient.
	Total.	Increase.	Total.	Increase.	Total.	Increase.	
	grams.	*grams.*	*grams.*	*grams.*	*cals.*	*cals.*	
0 to 1 hour[2]	30.0	6.5	26.5	6.0	91	12	0.82
1 to 2 hours	29.5	6.0	24.5	4.0	82	3	.87
2 to 3 hours	29.0	5.5	23.5	3.0	83	4	.90
Total	88.5	18.0	74.5	13.0	256	19	....

[1]Heat eliminated corrected for change in body-weight, but not for change in body-temperature.
[2]Subject finished eating 30 minutes after the beginning of this period. The eating occupied 18 minutes.

BANANAS.

In February 1910, three experiments were made in Boston with bananas only. One of the subjects had been used in two of the series of experiments previously considered.

F. M. M., February 8, 1910 (400 grams bananas, with a fuel value of 406 calories).—In the first two periods there were small increases in the carbon-dioxide production with essentially a basal metabolism in the last two periods. (See table 117.) A slight rise in the oxygen consumption in the first period was in large part compensated by values slightly less than basal in the last three periods. The same general picture was observed with the heat production. The respiratory

quotients were very irregular, but no extraordinarily high values were obtained. No pronounced effect upon either the gaseous metabolism or the heat production as a result of the ingestion of bananas is apparent in this experiment.

TABLE 117.—*F. M. M., February 8, 1910. Sitting.* (1-hour periods.)

Bananas:
Amount, 400 grams; nitrogen, 0.83 gram; total energy, 413 cals.
Fuel value: Total, 406 cals.; from protein, 5 p. ct.; from fat, 6 p. ct.; from carbohydrates, 89 p. ct.
Nitrogen in urine, 0.46 gram per hour.
Basal values (February 8, 1910): CO_2, 25.5 grams; O_2, 22.5 grams; heat,[1] 82 cals.; respiratory quotient, 0.83. Nitrogen in urine, 0.45 gram per hour.

Time elapsed since subject finished eating.	Carbon dioxide.		Oxygen.		Heat.[1]		Respiratory quotient.
	Total.	Increase.	Total.	Increase.	Total.	Increase.	
	grams.	*grams.*	*grams.*	*grams.*	*cals.*	*cals.*	
0 to 1 hour[2]	30.0	4.5	28.0	5.5	91	9	0.78
1 to 2 hours	28.5	3.0	22.0	−0.5	79	−3	.94
2 to 3 hours	25.5	0.0	21.5	−1.0	80	−2	.86
3 to 4 hours	26.0	0.5	20.0	−2.5	76	−6	.95
Total	110.0	8.0	91.5	1.5	326	−2	....

[1]Heat eliminated corrected for change in body-weight, but not for change in body-temperature.
[2]Subject finished eating 17 minutes after the beginning of this period. The eating occupied 10 minutes.

Dr. H., February 14, 1910 (403 grams bananas, with a fuel value of 409 calories).—According to the data given in table 118, noticeable increases in the carbon-dioxide production, oxygen consumption, and computed heat production were found. The respiratory quotients were all above 0.90.

TABLE 118.—*Dr. H., February 14, 1910. Sitting.* (1-hour periods.)

Bananas:
Amount, 403 grams; nitrogen, 0.83 gram; total energy, 416 cals.
Fuel value: Total, 409 cals.; from protein, 5 p. ct.; from fat, 6 p. ct.; from carbohydrates, 89 p. ct.
Basal values (February 14, 1910): CO_2, 22 grams; O_2, 20 grams; heat (computed), 66 cals.; respiratory quotient, 0.81. Nitrogen in urine, 0.33 gram per hour.

Time elapsed since subject finished eating.	Nitrogen in urine per hour.	Carbon dioxide.		Oxygen.		Heat (computed).		Respiratory quotient.
		Total.	Increase.	Total.	Increase.	Total.	Increase.	
	gram.	*grams.*	*grams.*	*grams.*	*grams.*	*cals.*	*cals.*	
0 to 1 hour[1]	0.51	27.0	5.0	21.5	1.5	73	7	0.91
1 to 2 hours	.51	28.0	6.0	22.5	2.5	77	11	.90
2 to 3 hours	.44	28.5	6.5	21.5	1.5	75	9	.95
Total	...	83.5	17.5	65.5	5.5	225	27	....

[1]Subject finished eating 22 minutes after the beginning of this period. The eating occupied 14 minutes.

Dr. H., February 17, 1910 (397 grams bananas, with a fuel value of 403 calories).—There was a marked increase in the carbon-dioxide production in all of the four periods. (See table 119.) The oxygen consumption showed considerable irregularity, although the results as a whole indicated a definite increase. The computations of heat production also gave irregular results, but on the average showed a distinct increase. While this experiment can not be considered as a good duplicate of the experiment on February 14, yet they both imply an increased metabolism as a result of eating bananas.

TABLE 119.—*Dr. H., February 17, 1910. Sitting.* (1-hour periods.)

Bananas:
Amount, 397 grams; nitrogen, 0.83 gram; total energy, 410 cals.
Fuel value: Total, 403 cals.; from protein, 5 p. ct.; from fat, 6 p. ct.; from carbohydrates, 89 p. ct.
Basal values (February 17, 1910): CO_2, 21.5 grams; O_2, 20.5 grams; heat (computed), 67 cals.; respiratory quotient, 0.77. Nitrogen in urine, 0.30 gram per hour.

Time elapsed since subject finished eating.	Nitrogen in urine per hour.	Carbon dioxide.		Oxygen.		Heat (computed).		Respiratory quotient.
		Total.	Increase.	Total.	Increase.	Total.	Increase.	
	gram.	*grams.*	*grams.*	*grams.*	*grams.*	*cals.*	*cals.*	
0 to 1 hours[1]..	0.43	25.5	4.0	22.0	1.5	74	7	0.83
1 to 2 hours...	.43	27.0	5.5	20.0	−0.5	69	2	.98
2 to 3 hours...	.37	28.0	6.5	24.0	3.5	81	14	.85
3 to 4 hours...	.37	24.5	3.0	18.5	−2.0	65	−2	.96
Total....	...	105.0	19.0	84.5	2.5	289	21	....

[1]Subject finished eating 19 minutes after the beginning of this period. The eating occupied 10 minutes.

POPCORN.

The use of an insoluble carbohydrate in a fruit (banana) presented certain facilities for the absorption and digestion of carbohydrate that would not obtain if starch were given. To approximate starch and still make the diet fairly palatable, we used popcorn in two of the Middletown experiments.

H. B. W., April 9, 1907 (187 grams popcorn, with a fuel value of 796 calories).—A basal value obtained 5 days before the experiment was used for comparison. Decided increments in the carbon-dioxide production are recorded in table 120 for all periods. A positive increment in oxygen consumption was noted in the first period, with slight fluctuations above or below the basal value in the three remaining periods. An increment in heat production was noted in all four periods, this paralleling the increment found in the carbon-dioxide excretion. The respiratory quotient was high throughout the entire experiment.

A. H. M., April 10, 1907 (199 grams popcorn, with a fuel value of 847 calories).—In the second experiment with popcorn an increment

TABLE 120.—*H. B. W., April 9, 1907. Sitting.* (2-hour periods.)

Popcorn:
Amount, 187 grams; nitrogen, 3.26 grams; total energy, 824 cals.
Fuel value: Total, 796 cals.; from protein, 11 p. ct.; from fat, 11 p. ct.; from carbohydrates, 78 p. ct.
Nitrogen in urine, 0.88 gram per 2 hours.
Basal values (April 4, 1907): CO_2, 54 grams; O_2, 46 grams; heat, 158 cals.

Time elapsed since subject finished eating.[1]	Carbon dioxide.		Oxygen.		Heat.		Respiratory quotient.
	Total.	Increase.	Total.	Increase.	Total.	Increase.	
	grams.	*grams.*	*grams.*	*grams.*	*cals.*	*cals.*	
1 to 3 hours.....	65	11	53	7	174	16	0.90
3 to 5 hours.....	63	9	46	0	167	9	.98
5 to 7 hours.....	58	4	44	−2	167	9	.96
7 to 9 hours.....	60	6	48	2	163	5	.89
Total.....	246	30	191	7	671	39	....

[1]Subject ate popcorn in 53 minutes.

was found in both the carbon-dioxide production and the oxygen consumption for all of the four periods, that for the oxygen consumption being fairly constant. (See table 121.) There was also an increase in the heat production in the first three periods. The respiratory quotient was very high in the first period, then gradually lowered. The positive increments in the carbon-dioxide excretion and heat production in both experiments with popcorn indicate that the ingestion of this food material has a definite effect upon the metabolism.

TABLE 121.—*A. H. M., April 10, 1907. Sitting.* (2-hour periods.)

Popcorn:
Amount, 199 grams; nitrogen, 3.47 grams; total energy, 877 cals.
Fuel value: Total, 847 cals.; from protein, 11 p. ct.; from fat, 11 p. ct.; from carbohydrates, 78 p. ct.
Basal values (March 6 and 9, 1907): CO_2, 51 grams; O_2, 46 grams; heat, 164 cals.

Time elapsed since subject finished eating.[1]	Nitrogen in urine per 2 hours.	Carbon dioxide.		Oxygen.		Heat.		Respiratory quotient.
		Total.	Increase.	Total.	Increase.	Total.	Increase.	
	grams.	*grams.*	*grams.*	*grams.*	*grams.*	*cals.*	*cals.*	
¾ to 2¾ hours.	1.22	67	16	49	3	187	23	1.01
2¾ to 4¾ hours.	1.24	62	11	50	4	188	24	.89
4¾ to 6¾ hours.	1.24	58	7	51	5	182	18	.84
6¾ to 8¾ hours.	1.02	57	6	50	4	165	1	.82
Total....	....	244	40	200	16	722	66	....

[1]Subject ate popcorn in 1¼ hours.

RICE.

The changes in the metabolism due to the ingestion of boiled rice were also studied in one experiment in Middletown.

A. L. L., May 27, 1907 (652 grams rice, with a fuel value of 432 calories).—As shown in table 122, the carbon-dioxide production was increased in the first two periods only. Owing to defective technique, it was necessary to combine the results for the oxygen consumption in the second and third periods; practically no increment in this factor was noted. A slight increment in the heat production was found in the first period, but the subsequent results differed but little from the basal value. The respiratory quotients for the first 6 hours were 1 or over. While an increment in the carbon-dioxide production characteristic of carbohydrate metabolism is shown clearly in the first two periods, there was no indication in the results obtained for either the oxygen consumption or the heat production that the metabolism increased noticeably as a result of the ingestion of the rice.

TABLE 122.—*A. L. L., May 27, 1907. Sitting.* (2-hour periods.)

Rice (boiled):
Amount, 652 grams; nitrogen, 2.03 grams; total energy, 449 cals.
Fuel value: Total, 432 cals.; from protein, 12 p. ct.; from fat, 1 p. ct.; from carbohydrates, 87 p. ct.
Nitrogen in urine, 0.71 gram per 2 hours.
Basal values (May 4, 1907): CO_2, 51 grams; O_2, 43 grams; heat,[1] 158 cals.

Time elapsed since subject finished eating.[2]	Carbon dioxide.		Oxygen.		Heat.		Respiratory quotient.
	Total.	Increase.	Total.	Increase.	Total.	Increase.	
	grams.	*grams.*	*grams.*	*grams.*	*cals.*	*cals.*	
½ to 2½ hours.....	66	15	46	3	168	10	1.05
2½ to 4½ hours.....	62	11	83	−3	311	−5	1.00
4½ to 6½ hours.....	52	1					
6½ to 8½ hours.....	51	0	42	−1	160	2	.89
Total.....	231	27	171	−1	639	7	....

[1]Heat eliminated corrected for change in body-weight, but not for change in body-temperature.
[2]Subject ate rice in 20 minutes.

GENERAL DISCUSSION OF CALORIMETER EXPERIMENTS WITH CARBOHYDRATES.

In the foregoing discussion of the individual calorimeter experiments certain features common to each were pointed out. From the results given in tables 101 to 122, we may conclude that the effect on the carbon-dioxide excretion was relatively uniform in that a marked increase in the first 1-hour or 2-hour period was followed by considerable increases which gradually decreased in magnitude as the experiment progressed. With the oxygen consumption the increment, when noted, was almost invariably in the first period; subsequent periods showed such irregularity in values as to allow no other inference than that probably the base-line had been reached. With the heat production an increment was again definitely observed, usually in the first period, subsequent periods showing slight fluctuations either above or below the basal value.

The conclusion, then, may fairly be drawn that the ingestion of carbohydrate material has a pronounced and continuous effect upon the carbon-dioxide production, which may last 8 hours or more, and increases the oxygen consumption for a short time, generally a little over 2 hours. The respiratory quotient also shows a marked rise. The increase in the oxygen consumption is paralleled by a definite increase in the heat production. The last observation is of the greatest significance in connection with calorimeter experiments, as it demonstrates by direct calorimetry a positive increase in the heat production as the result of the ingestion of varying amounts of carbohydrates.

MAXIMUM EFFECT OF CARBOHYDRATE INGESTION ON METABOLISM (DIRECT CALORIMETRY).

To what extent the basal heat production may be increased as a result of carbohydrate ingestion may best be shown by considering the data in table 123. In this table the results are grouped according to the carbohydrates studied. The amounts ingested, the total length of observation, and the maximum increase above the basal value are here recorded. The length of time between the taking of the food and the maximum increase is also noted.

Unfortunately the calorimeter experiments are not sufficiently numerous, either as to the number of experiments with each carbohydrate or the number with the same amounts of food, to permit satisfactory comparisons of the relation of the individual carbohydrates to the maximum heat production. It is much to be regretted, also, that more experiments with pure carbohydrates were not made instead of with such mixed carbohydrates as bananas, popcorn, and rice. At the time these studies were made, however, the main purpose was to determine the possible maximum effect of carbohydrate ingestion upon the basal heat production. This is clearly established, as will be seen from the results given in the table. Although, with the possible exception of bananas and sugar, the evidence is not sufficiently complete to allow deductions as to the differences between the individual carbohydrates, the general picture is tolerably clear.

With sucrose it will be seen that the largest amount of heat was produced when the largest amount was ingested. This occurred in the experiment with A. H. M. on April 1, 1907, in which the period of experimenting was 8 hours, subdivided into four 2-hour periods. In this experiment an increment of 17 per cent was found in the period from $\frac{1}{4}$ to $2\frac{1}{4}$ hours after food. A smaller amount of sugar taken by F. M. M. on January 31, 1910, produced an increment of but 11 per cent within one hour of taking the sugar, while a still smaller amount with A. W. W. produced an increase of 8 per cent in approximately the same time. In all cases the maximum increment was found from $\frac{1}{4}$ to $2\frac{1}{4}$ hours or even less after the ingestion of the carbohydrate.

TABLE 123.—*Maximum effect of carbohydrate ingestion on heat production.* (Calorimeter experiments.)

Carbohydrate.	Amount.	Subject.	Date.	Length of observation.	Greatest increment above basal value.	Time elapsed since subject finished eating.
	grams.			*hours.*	*p. ct.*	*hours.*
Sucrose	191	A. H. M.	Apr. 1, 1907	8	17	¼ to 2¼
	100[2]	F. M. M.	Jan. 31, 1910	5	11	0 to 1
	100[2]	F. M. M.	Feb. 2, 1910	4	9	0 to 1
	80	A. W. W.	May 28, 1907	4	8	¼ to 1¼
Maltose-dextrose mixture	458	Dr. R...	Feb. 21, 1907	8	16	4¼ to 6¼
	431	E. H. B..	May 14, 1907	8	11	0 to 2
	307	A. H. M.	Mar. 28, 1907	8	28	½ to 2½
	299	A. L. L..	May 13, 1907	8	13	¼ to 2¼
	145[2]	J. J. C...	Mar. 4, 1910	4	28	1 to 2
Bananas and sugar:						
Bananas	1173	H. R. D.	Mar. 31, 1906	8	31	0 to 2
Sugar	103					
Bananas	1171	H. R. D.	Apr. 21, 1906	10	27	2¼ to 4¼
Sugar	103					
Bananas	1121	A. H. M.	Apr. 2, 1906	8	28	0 to 2
Sugar	86					
Bananas	765	A. L. L..	Mar. 30, 1906	8	34	0 to 2
Sugar	99					
Bananas	763	A. L. L..	Apr. 19, 1906	12	31	¼ to 2¼
Sugar	99					
Bananas	648	J. J. C...	Apr. 7, 1909	4	26	2 to 3
Sugar	77					
Bananas	611	F. M. M.	Apr. 8, 1909	3	15	0 to 1
Sugar	9					
Bananas	403	Dr. H...	Feb. 14, 1910	3	17	1 to 2
	400	F. M. M.	Feb. 8, 1910	4	11	0 to 1
	397	Dr. H...	Feb. 17, 1910	4	21	2 to 3
Popcorn	199	A. H. M.	Apr. 10, 1907	8	15	2¾ to 4¾
	187	H. B. W.	Apr. 9, 1907	8	10	1 to 3
Rice	652	A. L. L..	May 27, 1907	8	6	½ to 2½

[1]The time given represents the experimental period. The food was usually taken less than half an hour before the beginning of the experiment. See tables 101 to 122 for details.
[2]Also juice of one lemon.

Unlike the experiments with sucrose, the maltose-dextrose experiments did not show the highest increment with the largest amount, as the greatest increase (28 per cent) was found with only 145 grams. The first two experiments recorded with the maltose-dextrose mixture are comparable in that the amounts of carbohydrate ingested are approximately the same and show an average increment of 13 to 14 per cent. In one of these experiments, that with Dr. R., the maximum effect was not observed until 4¼ to 6¼ hours after the food was taken. As this subject was particularly satisfactory from the standpoint of technique, we have no explanation for this long-delayed action in securing the maximum value. Two other experiments, which were made with approximately 300 grams of the sugar mixture, do not give very

satisfactory duplicate results, as the value found with A. H. M. is more than twice as large as that found with A. L. L., although the time of appearance is practically the same, *i. e.*, in the first 2 hours after food. In comparing the values in this group, it should be noted that in the calculation of the percentage increment the base-line used for J. J. C. was 1 hour, while that for the other subjects of the experiments with maltose-dextrose mixture was 2 hours.

The first three experiments with bananas and sugar are perfectly comparable in that practically the same amounts of bananas and sugar were given in each case. The increment is strikingly constant, varying only from 27 to 31 per cent. In the two experiments with A. L. L., the amounts ingested were approximately the same and reasonably concordant increments were obtained, *i. e.*, 34 and 31 per cent respectively. With somewhat smaller amounts of bananas and sugar, J. J. C. gave an increment of but 26 per cent, while F. M. M., with an ingestion of 611 grams bananas and 9 grams of sugar, showed an increment of but 15 per cent.

In three experiments the ingestion of approximately 400 grams of bananas, without sugar, gave an increase in the heat production of 11 to 21 per cent, while in two experiments with popcorn a positive increment of 10 to 15 per cent was found. The experiment with boiled rice showed an increase of 6 per cent.

In considering these data it should be remembered that the results for the individual experiments can have but relatively little value, inasmuch as the amounts recorded for the greatest increments above basal requirements represent the observations in a single period and are thus liable to all the errors possible with such measurements. The emphasis should therefore be laid upon the general picture. The values given in this table show that it is perfectly possible for a pure sugar, such as sucrose, to increase the metabolism 17 per cent above the basal value; that a maltose-dextrose mixture can raise it somewhat higher; that bananas and sugar taken together give an increment of 15 to 34 per cent, depending upon the amount ingested; that bananas without sugar increase the heat production on the average 16 per cent; and that popcorn and rice may produce an increment of approximately 13 and 6 per cent respectively. In other words, it is very clear that large increments in the heat production may be expected from a practically protein-free diet. As these values deal only with the maximum periods, they simply show to what extent the basal value may actually be stimulated by the metabolic processes following the ingestion of pure or nearly pure carbohydrates.

The time at which the maximum effect appears is likewise of great importance. An examination of the figures given in the last column shows that in all but a few instances the highest value appeared in the first 2 hours. The most notable exceptions to this are the experiments

with Dr. R., February 21, 1907, with the maltose-dextrose mixture; H. R. D., April 21, 1906, with bananas and sugar; and A. H. M., April 10, 1907, with popcorn.

The general conclusions from this series of calorimeter experiments would therefore be that the ingestion of pure or nearly pure carbohydrate produces a positive increase in the metabolism which for short periods, at least, may amount to almost 35 per cent, and that this increase nearly always takes place in the first 2 hours of experimentation. An examination of tables 101 to 122 shows clearly that results obtained in the periods subsequent to the first 2 hours of the experiment give very little, if any, evidence as to the nature of the metabolism, save that a persistent increase in the carbon-dioxide production is usually found. It is of particular significance, however, that in the majority of the experiments direct calorimetry shows definitely an increment in the heat production due to the ingestion of carbohydrates; we can therefore consider this fact as established. The value of this known fact will be more apparent when an analysis is attempted of the intermediary processes involved in the metabolism of carbohydrate.

On the other hand, we are not able from these calorimeter experiments to determine with great exactness the time relations between the ingestion of carbohydrate and the metabolism. While they bring out the fact that the maximum effect of carbohydrate ingestion appears in the first 2 hours and that thereafter practically no effect is noted in the majority of instances save in the production of carbon dioxide, experiments made with shorter periods are absolutely essential for a more careful analysis of the relationship. For these determinations in shorter periods recourse must be had to the long series of observations in the respiration experiments with carbohydrates, from which an estimation may be made by indirect calorimetry of the course of the metabolism after carbohydrate ingestion.

TOTAL INCREMENTS IN METABOLISM AFTER CARBOHYDRATE INGESTION (DIRECT CALORIMETRY).

The discussion thus far has dealt primarily with the extent to which the basal metabolism may be increased temporarily by the ingestion of varying amounts of carbohydrates and the time relations between the maximum increase and the time of ingestion. As a casual examination of tables 101 to 122 will show, the increase in the heat production after carbohydrate ingestion is, for the most part, only found in the first hour or two. In a number of the experiments the increment continues longer than the first period; it is thus important to note not simply the highest point to which the basal metabolism may be lifted by the ingestion of carbohydrate, but likewise the total effect of the carbohydrate upon the basal metabolism. This can be done only by

noting the total increment in the heat production. This increment is secured by measuring the total heat produced during the whole experiment and computing from the basal heat production the increment actually obtained in this period. The values found in the calorimeter experiments for the total increment in heat production after the ingestion of carbohydrate are given in table 124; in the last column of this table are also recorded the percentages of the total increments in terms of the basal value. The values for the basal heat production are included for purposes of comparison.

TABLE 124.—*Total increment in heat production following ingestion of carbohydrate.*
(Calorimeter experiments.)

Carbohydrate.	Amount.	Subject.	Date.	Length of observation.[1]	Heat measured in period of observation.		
					Basal value.	Increment above basal value.	
						Total amount.	Per cent.
	grams.			*hours.*	*cals.*	*cals.*	
Sucrose	191	A. H. M.	Apr. 1, 1907	8	656	68	10
	[2]100	F. M. M.	Jan. 31, 1910	5	400	19	5
	[2]100	F. M. M.	Feb. 2, 1910	4	312	16	5
	80	A. W. W.	May 28, 1907	4	312	6	2
Maltose-dextrose mixture	458	Dr. R.	Feb. 21, 1907	8	584	74	13
	431	E. H. B.	May 14, 1907	8	716	39	5
	307	A. H. M.	Mar. 28, 1907	8	656	94	14
	299	A. L. L.	May 13, 1907	8	632	40	6
	[2]145	J. J. C.	Mar. 4, 1910	4	296	41	14
Bananas and sugar:							
Bananas	1,173	H. R. D.	Mar. 31, 1906	8	584	107	18
Sugar	103						
Bananas	1,171	H. R. D.	Apr. 21, 1906	10	730	137	19
Sugar	103						
Bananas	1,121	A. H. M.	Apr. 2, 1906	8	568	94	17
Sugar	86						
Bananas	765	A. L. L.	Mar. 30, 1906	8	580	88	15
Sugar	99						
Bananas	763	A. L. L.	Apr. 19, 1906	12	888	72	8
Sugar	99						
Bananas	648	J. J. C.	Apr. 7, 1909	4	288	69	24
Sugar	77						
Bananas	611	F. M. M.	Apr. 8, 1909	3	237	19	8
Sugar	9						
Bananas	403	Dr. H.	Feb. 14, 1910	3	198	27	14
	400	F. M. M.	Feb. 8, 1910	4	328	−2	−1
	397	Dr. H.	Feb. 17, 1910	4	268	21	8
Popcorn	199	A. H. M.	Apr. 10, 1907	8	656	66	10
	187	H. B. W.	Apr. 9, 1907	8	632	39	6
Rice	652	A. L. L.	May 27, 1907	8	632	7	1

[1]The time given represents the experimental period. The food was usually taken less than half an hour before the beginning of the experiment. See tables 101 to 122 for details.
[2]Also juice of one lemon.

It is very difficult to obtain a satisfactory method for computing the percentage increment. Obviously the lengthening of the period in which the measurements are made without an increment above the basal metabolism simply increases the denominator of the fraction and thus increases the basal value without affecting the increment. The value of the increment in terms of per cent is thus decreased. In table 123 it will be seen that the percentage for the greatest increment above the basal value is in every instance considerably higher than the percentage for the total increment given in the last column of table 124. This is due in large part to the fact that the total increment in the heat production took place during the first hour or two, while in the subsequent hours the metabolism was essentially the same as the basal value.

When the duration of the experiment is 12 hours instead of 4, 5, or 8 hours, as the case may be, the percentage total increment is naturally greatly decreased. A striking illustration of this is shown by comparing the experiments with A. L. L., on March 30, 1906, and April 19, 1906, in which essentially the same amounts of bananas and sugar were given. The greatest increment was 34 per cent in one case and 31 per cent in the other; in both experiments this increment occurred in some part of the first or second hour. The total increment above the basal value was found to be 88 calories in one case and 72 calories in the other. There was, however, a difference in the basal values of the two experiments of over 300 calories, owing to the fact that in the April experiment the length of the experimental period was 12 hours, while in the March experiment it was only 8 hours. The percentage increment in the March experiment was therefore nearly double that in the April experiment, while in other experiments the values are fairly good duplicates.

The computation of the total increment above the basal value for experiments in which food was ingested is justifiable. The computation of the percentage of the increment is, however, open to serious criticism, and it is difficult to see how such percentages can have real significance. Yet they are frequently computed and reported in experiments of this kind. Perhaps their greatest value for this discussion is the fact that while in these observations the experimental period varied in length only from 3 to 12 hours, and usually from 4 to 8 hours, it can readily be seen that were the remainder of the 24 hours added to the experimental period, the percentage value would be greatly decreased and, in fact, would nearly disappear. It can easily be understood, therefore, why investigators employing the 24-hour period have failed to note a material increase in the metabolism due to the ingestion of carbohydrates, for although there is a distinct temporary increase, which may at times reach 30 per cent or over, this increase, when compared to the total 24-hour basal value, appears almost insignificant. If, on the contrary, we are dealing with a substance which is delayed

in effect, even though its intensity may not be so great as that noted in some of our experiments, the use of the base-line for the longer period would be more justifiable and more truly indicative of the actual conditions than a base-line for a short period. Accordingly, while the values given in table 123 for the greatest increment above the basal metabolism may not be taken as indicating a prolonged effect at this level of intensity and should only be interpreted as the possible maximum level to which the basal value may be raised, the percentage values in table 124 must be interpreted by taking into consideration simultaneously not only the total amount of increment measured but the basal value and particularly the length of the experimental period. As uniformity in results may not be expected with experiments of different length, these percentage values can have but little relative mathematical significance other than to explain the low values noted by investigators during 24-hour periods when carbohydrates are given.

Although the experiments with pure carbohydrates are better adapted for comparison purposes than those with mixed carbohydrates, the discussion of the total increments in the metabolism as a result of the ingestion of the former will be deferred until the results of the respiration experiments are considered, as by far the larger number of experiments with the pure carbohydrates were made with the respiration apparatus. Still it is of significance to note from table 124 that with sucrose the total increment above the basal value for the entire period of measurement was 10 per cent in one case, and with the maltose-dextrose mixture it was 14 per cent in two cases.

The percentages for the total increment above the basal value as computed for the mixed carbohydrates are likewise shown in table 124. The starch as ingested in the experiments with mixed carbohydrates was in three forms: first, in popcorn, which was dry and hence must undergo the process of imbibition in the stomach; second, in rice, which was cooked; and third, in the moist starch of bananas. The popcorn experiments were primarily designed to throw some light upon the ingestion of roughage in the diet and those with rice to give the effect of cooked starch. The effect of uncooked starch was studied with bananas, of which large amounts could be eaten with considerable ease. As carried out, however, the experimental method was somewhat faulty in that the bananas were given, in all but three experiments, with relatively large amounts of cane sugar; hence we have unquestionably a double influence upon the metabolism.

Total increments for bananas and sugar are frequently found of 17 to 24 per cent, showing very perceptibly the influence of the ingestion of this mixture of carbohydrates. No great stress should be laid upon these computations, owing to the irregularities in the length of the observations and the fact that frequently the metabolism returned to the basal value before the experiment ended. Nevertheless, the gen-

eral picture shown for bananas and sugar is that of a very pronounced increase in heat production following their ingestion, which may rise in individual periods to a peak of 34 per cent, with a total increment above the basal value as high as 24 per cent and frequently 15 or more per cent, values which are considerably above those normally noted with pure carbohydrates. The effect following the ingestion of cane sugar is very pronounced; a considerable effect is likewise found with bananas. The high values obtained with the combined bananas and sugar point definitely to the conclusion that we have here an effect due to cane sugar which is superimposed upon the effect due to the large amount of carbohydrate taken simultaneously in the form of fruit.

The experiments with bananas without sugar gave results which are irregular; two showed a measurable increment, while in the other no increment was obtained. The two experiments with popcorn indicate a distinctly higher metabolism as a result of the ingestion of this material. But one experiment was made with rice, a fact which is to be regretted, since the slight increment noted, namely, 7 calories, should be confirmed. It is evident that our section of this research dealing with carbohydrates of a gross texture and the possible effect of roughage in the diet is altogether too limited for adequate discussion.

RESPIRATION EXPERIMENTS.

As the research on the influence of the ingestion of food progressed, it became evident that measurements of the metabolism in short periods were essential, for many of the experiments indicated a somewhat rapid change in the character of the metabolism following the ingestion of carbohydrate. Experiments with periods of sufficiently short duration to show this rapid change were impracticable with an apparatus so large as the respiration calorimeter in Middletown. With the development and subsequent completion in the Nutrition Laboratory of the so-called "universal respiration apparatus"[1] observations could readily be made in short periods with fairly satisfactory results. An extended series of such experiments was begun in the fall of 1910 and continued at intervals for several years. We are indebted to Mr. H. L. Higgins[2] and Mr. L. E. Emmes for their kind coöperation, as the majority of the experiments made in 1911 were under their immediate supervision. The experiments previous to 1912 were made with the so-called "tension-equalizer" form of the respiration apparatus,[3] which was later replaced by the spirometer type of the same apparatus. Both types of the apparatus have been carefully

[1]This apparatus is described in detail by Benedict, Deutsch. Arch. f. klin. Med., 1912, **107**, pp. 156–200; also Carpenter, Carnegie Inst. Wash. Pub. No. 216, 1915, pp. 21–53.

[2]See, also, Higgins, Am. Journ. Physiol., 1916, **41**, p. 258.

[3]Carpenter, Carnegie Inst. Wash. Pub. No. 216, 1915, p. 21, and Benedict, Am. Journ. Physiol., 1909, **24**, p. 345.

tested by one of us[1] and their capacity for yielding accurate results has been proved.

The universal respiration apparatus measures both the carbon-dioxide excretion and the oxygen consumption, and special records are made of the pulse rate and the respiration rate. The spirometer form of the apparatus also gives a record of the ventilation of the lungs. Although the heat production is not measured by this apparatus, it has been computed by the indirect method from the measurements of the oxygen consumption by means of the factors for non-protein quotients of Zuntz and Schumburg.[2] It should be stated that in this computation no correction was made for the heat resulting from the combustion of protein and the actual non-protein quotients were not

TABLE 125.—*Comparison of values for heat as computed with observed and non-protein quotients.* (Values per minute.)

K. H. A., May 18, 1912.[1]				P. F. J., May 22, 1912.[1]			
Respiratory quotient.		Heat.		Respiratory quotient.		Heat.	
Observed.	Non-protein.	Uncorrected.	Corrected for protein.	Observed.	Non-protein.	Uncorrected.	Corrected for protein.
		cals.	*cals.*			*cals.*	*cals.*
0.82[2]	0.83[2]	1.05[2]	1.03[2]	0.91[2]	0.93[2]	1.12[2]	1.10[2]
.94	.99	1.24	1.22	1.07	1.12	1.16	1.13
1.00	1.08	1.19	1.15	1.11	1.16	1.20	1.18
.97	1.03	1.20	1.17	1.03	1.07	1.24	1.22
.92	.97	1.12	1.10	1.00	1.04	1.24	1.21
.91	.95	1.07	1.04	.96	.99	1.23	1.22
.86	.88	1.03	1.01	.93	.96	1.12	1.11

[1]See tables 140 and 145, pp. 212 and 213. Diet: 100 grams levulose, with juice of one lemon.
[2]Basal value; average of 3 periods.

computed. Magnus-Levy[3] has shown that only a slight error of approximately 3 per cent results from neglecting to compute the protein metabolism in indirect calorimetry. The small variations due to the use of the determined quotients in our computations are illustrated by the comparison made in table 125. It has therefore not seemed justifiable to recompute the heat values on the basis of the non-protein respiratory quotient, especially as the results had only a differential significance in this study and the increment above the basal value was the special object of the computations. In most cases, the respiratory quotients as determined are but 2 to 5 points lower than the non-protein respiratory quotients. With the high-nitrogen diets, the differences are even smaller.

[1]Carpenter, Carnegie Inst. Wash. Pub. No. 216, 1915, pp. 111 and 227.
[2]Zuntz and Schumburg, Physiologie des Marsches, 1901, p. 361.
[3]See Loewy, Oppenheimer's Handbuch der Biochemie, 1911, **4** (1), p. 281; also Magnus-Levy, von Noorden's Handbuch der Pathologie des Stoffwechsels, 1896, **1**, p. 207.

In practically all of the observations with the respiration apparatus, the basal value was determined each day just prior to the ingestion of the carbohydrate studied, usually as a result of 2 to 4 well-agreeing periods. From the results obtained with the calorimeter experiments, it was clear that a greatly increased production of carbon dioxide was to be expected after the ingestion of the carbohydrate and that this might persist for some time, but that the increase in the oxygen consumption would probably not continue for a great length of time. Hence most of our respiration experiments were terminated 3 to 4 hours after the ingestion of the carbohydrate; occasionally some experiments were even shorter than this. In no instance were the experiments continued for 8 hours, as was frequently the case in the calorimeter experiments. The periods were usually 15 minutes long, but in one or two experiments they were much shortened for the purpose of studying the rapid fluctuations in the respiratory quotient.[1]

Only pure carbohydrates were used in the respiration experiments, *i. e.*, dextrose, levulose, sucrose, and lactose. These carbohydrates may be considered as chemically pure products, save that levulose and lactose contain a small percentage of water.[2] The amounts given were in practically every experiment either 100 or 75 grams. In many of the experiments the sugars were taken in solution, water and varying amounts of lemon juice being added. As a rule, the juice of one-half or a whole lemon was used, this being approximately 20 or 40 grams.

A large number of subjects were studied and sufficient data secured to draw general deductions, but it should be borne in mind that the individual values must not be considered as indicative of the individuality of the subject or of any particular abnormality. With the universal respiration apparatus, duplicate gas analyses are not made; the measurements of the carbon-dioxide production and oxygen consumption for each period therefore represent only individual determinations. This fact should be especially emphasized, as with practically all other forms of respiration apparatus duplicate gas analyses are the rule.

STATISTICS OF RESPIRATION EXPERIMENTS.

With so large a number of respiration experiments, it seems needless to discuss them individually; hence only the statistical data are given here, grouped according to the carbohydrate used, with the idea of including the results later in general summary tables and discussing not only the influence of the individual carbohydrates upon the basal metabolism, but likewise the effect of variations in the amounts ingested. The preliminary experiments with the universal respiration apparatus on the influence of the ingestion of food were made with the

[1] See, for instance, tables 134 and 146, pp. 209 and 214.

[2] The levulose contained 4.8 per cent moisture; lactose having one molecule of crystallization was always used.

coöperation of Professor Otto Cohnheim, formerly of Heidelberg, who kindly volunteered as a subject while he was a guest of the Nutrition Laboratory in the fall of 1909. The details of the experiments with Professor Cohnheim are given in tables 154 and 155. The details of the whole series of respiration experiments following the ingestion of carbohydrates are given in tables 126 to 168. Statistical data not included in the tables are given in the following pages for a number of the experiments. When no further data are available, no mention is made of the experiment in the statistical text.

DEXTROSE EXPERIMENTS.

J. J. C., 9h47m a. m. to 4h05m p. m., March 7, 1911. 64.2 kilograms.—Very quiet in first basal period, probably slept a little; marked tendency to fall asleep in second period; in second, third, and sixth food periods, necessary for observer to speak to the subject often to prevent his falling asleep; in last food period, jumped violently once when aroused. Nitrogen in urine per hour 7h15m a. m. to 4h35m p. m., 0.30 gram.

L. E. E., 8h33m a. m. to 3h55m p. m., May 29, 1911. 59.2 kilograms.—Very quiet in first basal period; asleep a few moments before end of third period; somewhat restless in fourth basal period. Asleep a few moments in first and third food periods, also slept during intermissions between second and third food periods and between third and fourth food periods. Nitrogen in urine per hour 7h40m a. m. to 11h08m a. m., 0.46 gram; 11h08m a. m. to 12h57m p. m., 0.53 gram; 12h57m p. m. to 4h06m p. m., 0.31 gram.

C. H. H., 9h12m a. m. to 4h51m p. m., May 1, 1911. 55.5 kilograms. Very quiet and awake all periods; complained of nausea after taking dextrose. Nitrogen in urine per hour 7 a. m. to 5h03m p. m., 0.32 gram.

H. L. H., 8h40m a. m. to 3h54m p. m., May 24, 1911. 59.8 kilograms.—Very quiet and awake in basal periods; after taking dextrose, also very quiet and awake; very warm in seventh food period and asked to have electric fan set in motion. Nitrogen in urine per hour 7h35m a. m. to 11h30m a. m., 0.53 gram; 11h30m a. m. to 3h20m p. m., 0.44 gram.

P. F. J., 8h46m a. m. to 2 p. m., May 15, 1912. 56.8 kilograms.—Considerable movement between first and second food periods, also between third and fourth food periods. Nitrogen in urine per hour 7h30m a. m. to 2h05m p. m., 0.49 gram.

J. J. C., 11h04m a. m. to 2h24m p. m., December 22, 1910. 64.7 kilograms.—High-carbohydrate diet on previous day. Sat down at 10h47m a. m. in comfortable Morris chair, with foot-rest. Adhesive plaster used to secure perfect closure of mouth. In first basal period wide awake, but more sleepy as experiment continued; very sleepy in fourth basal period. After dextrose, awake all of first period but inclined to be drowsy near end; drowsiness increased in second food period; very sleepy in third food period; went to sleep in fourth food period, while observer was talking to him; occasional slight movements in sleep. Was cold at beginning of first food period and used blanket most of experiment. Nitrogen in urine per hour 8h15m a. m. to 2h33m p. m., 0.44 gram.

J. J. C., 9h05m a. m. to 5h29m p. m., December 28, 1910. 64.7 kilograms.—High-carbohydrate diet preceding day. Wooden head-rest used in experiment. Slept most of time in second and third basal periods, probably awake in last basal period. Slept most of third, fourth, and fifth food periods; no attempt made to keep him awake in fourth and fifth periods; probably awake in first and sixth food periods; very wide awake in seventh food period. Some pain

in stomach as a result of taking dextrose. Nitrogen in urine per hour 8^h10^m a. m. to 5^h32^m p. m., 0.40 gram.

V. G., 10^h54^m a. m. to 4^h14^m p. m., December 23, 1910. 55.1 kilograms.—Subject sitting in chair during experiment. Awake throughout basal periods; very restless in second basal, frequently looking at clock; very quiet in third basal period. Awake throughout food periods except in fourth, when he slept a little; very quiet in fifth period; after fifth and sixth food periods complained of difficulty in breathing through one nostril, also that left nostril was sore; allowed to rest a half hour between sixth and seventh food periods and asked to free his nose from all mucus before last period began. Nitrogen in urine per hour 7^h20^m a. m. to 4^h33^m p. m., 0.33 gram.

V. G., 9^h02^m a. m. to 3^h04^m p. m., December 29, 1910. 55.7 kilograms. High-carbohydrate diet on preceding day. Basal periods, awake in first period, much more sleepy in second, slept some in third, slight movement in fourth, absolutely quiet and awake in fifth period. After dextrose, sleepy in first period and possibly slept a little; awake and restless in third period, especially towards the end, drawing deep breaths; left nostril seemed clogged. Nitrogen in urine per hour 7^h50^m a. m. to 5^h25^m p. m., 0.36 gram.

TABLE 126.—*K. H. A., May 14, 1912. Lying.* (Values per minute.)

Dextrose: Amounts, 100 grams dextrose, juice of one lemon; energy, 385 cals.; from carbohydrates, 100 p. ct.

Time.	Ventilation (reduced).	Average respiration rate.	Carbon dioxide.	Respiratory quotient.	Oxygen.	Average pulse rate.	Heat (computed).
Without food:	*liters.*		*c.c.*		*c.c.*		*cals.*
Av. of 3 periods.	5.19	14.4	187	0.84	223	55	1.08
With food:[1]							
10^h20^m a.m.....	4.89	14.0	183	.85	216	49	1.05
10 55 a.m.....	6.12	14.3	235	.98	240	60	1.21
11 34 a.m.....	6.12	15.4	232	1.01	230	61	1.16
12 02 p.m.....	5.62	14.8	214	1.00	214	55	1.08
1 25 p.m.....	5.85	14.9	225	1.00	224	61	1.13
1 51 p.m.....	5.30	11.8	210	.89	235	57	1.15

[1]Subject drank dextrose and lemon juice in 325 c.c. of water at 10^h01^m a. m.

TABLE 127.—*J. C. C., December 31, 1912. Lying.* (Values per minute.)

Dextrose: Amounts, 100 grams dextrose, juice of half lemon; energy, 380 cals.; from carbohydrates, 100 p. ct.

Time.	Ventilation (reduced).	Average respiration rate.	Carbon dioxide.	Respiratory quotient.	Oxygen.	Average pulse rate.	Heat (computed).
Without food:	*liters.*		*c.c.*		*c.c.*		*cals.*
Av. of 3 periods.	5.41	12.6	187	0.74	252	62	1.19
With food:[1]							
11^h13^ma.m.....	5.48	12.2	196	.72	272	78	1.28
11 45 a.m.....	5.54	13.0	203	.77	264	71	1.26
12 17 p.m.....	5.68	13.3	208	.78	268	66	1.28
12 50 p.m.....	5.61	12.4	210	.78	269	65	1.28
1 32 p.m.....	5.42	12.3	205	.81	253	64	1.22
2 11 p.m.....	5.48	13.4	200	.81	247	63	1.19
3 04 p.m.....	5.36	14.9	178	.72	246	63	1.16

[1]Subject drank dextrose and lemon juice in 250 c.c. of water at 11^h05^m a. m.

TABLE 128.—*J. J. C., March 7, 1911. Lying.* (Values per minute.)

Dextrose: Amounts, 100 grams dextrose, juice of half lemon; energy, 380 cals.; from carbohydrates, 100 p. ct.

Time.	Average respiration rate.	Carbon dioxide.	Respiratory quotient.	Oxygen.	Average pulse rate.	Heat (computed).
Without food:		*c.c.*		*c.c.*		*cals.*
Av. of 4 periods..	16	184	0.79	232	59	1.11
With food:[1]						
12^h21^mp.m.....	17	215	.79	272	67	1.30
1 12 p.m.....	16	242	.89	271	66	1.33
1 48 p.m.....	15	240	.90	268	68	1.32
2 24 p.m.....	16	239	.92	261	68	1.29
2 56 p.m.....	18	222	.94	236	68	1.17
3 50 p.m.....	18	217	....	...	68	1.19

[1]Subject drank dextrose and lemon juice in 200 c.c. of water at 12^h08^m p. m.

TABLE 129.—*L. E. E., May 29, 1911. Lying.* (Values per minute.)

Dextrose: Amounts, 100 grams dextrose, juice of half lemon; energy, 380 cals.; from carbohydrates, 100 p. ct.

Time.	Average respiration rate.	Carbon dioxide.	Respiratory quotient.	Oxygen.	Average pulse rate.	Heat (computed).
Without food:		*c.c.*		*c.c.*		*cals.*
Av. of 4 periods..	13	183	0.78	236	57	1.13
With food:[1]						
10^h48^ma.m.....	14	195	.82	237	55	1.14
11 27 a.m.....	14	219	.88	250	60	1.23
12 01 p.m.....	16	230	.92	251	57	1.24
12 33 p.m.....	16	232	.91	255	57	1.26
1 30 p.m.....	16	237	.96	246	62	1.23
2 10 p.m.....	17	206	.91	227	59	1.12
2 57 p.m.....	15	203	.80	254	57	1.22
3 40 p.m.....	14	203	....	...	59	....

[1]Subject drank solution (325 c.c.) at 10^h32^m a. m.

TABLE 130.—*C. H. H., May 1, 1911. Lying.* (Values per minute.)

Dextrose: Amounts, 100 grams dextrose, juice of half lemon; energy, 380 cals.; from carbohydrates, 100 p. ct.

Time.	Average respiration rate.	Carbon dioxide.	Respiratory quotient.	Oxygen.	Average pulse rate.	Heat (computed).
Without food:		*c.c.*		*c.c.*		*cals.*
Av. of 3 periods..	14	167	0.87	193	60	0.94
With food:[1]						
11^h21^ma.m.....	12	197	.85	231	73	1.12
11 50 a.m.....	13	203	.91	224	63	1.11
12 22 p.m.....	12	186	.93	200	66	.99
12 54 p.m.....	14	193	.94	205	66	1.02
1 23 p.m.....	14	175	.82	214	62	1.03
2 05 p.m.....	14	179	.90	198	60	.97
3 50 p.m.....	15	180	.93	194	61	.96
4 36 p.m.....	15	177	.87	204	63	1.00

[1]Subject drank solution (325 c.c.) at 10^h45^m a. m.

TABLE 131.—*H. L. H., May 24, 1911. Lying.* (Values per minute.)

Dextrose: Amounts, 100 grams dextrose, juice of half lemon; energy, 380 cals.; from carbohydrates, 100 p. ct.

Time.	Average respiration rate.	Carbon dioxide.	Respiratory quotient.	Oxygen.	Average pulse rate.	Heat (computed).
Without food:		*c.c.*		*c.c.*		*cals.*
Av. of 4 periods..	13	183	0.82	224	56	1.08
With food:[1]						
11^h11^ma.m.....	15	189	.78	243	64	1.16
11 53 a.m.....	15	230	.91	252	64	1.24
12 30 p.m.....	16	219	.94	233	63	1.16
1 01 p.m.....	15	222	.98	227	65	1.14
1 42 p.m.....	16	215	.94	228	62	1.13
2 21 p.m.....	15	210	.94	223	64	1.11
2 55 p.m.....	15	222	.88	252	71	1.23
3 39 p.m.....	14	205	.80	256	62	1.23

[1]Subject drank solution (325 c.c.) at 10^h55^m a. m.

TABLE 132.—*P. F. J., May 15, 1912. Lying.* (Values per minute.)

Dextrose: Amounts, 100 grams dextrose, juice of one lemon; energy, 385 cals.; from carbohydrates, 100 p. ct.

Time.	Ventilation (reduced).	Average respiration rate.	Carbon dioxide.	Respiratory quotient.	Oxygen.	Average pulse rate.	Heat (computed).
Without food:	*liters.*		*c.c.*		*c.c.*		*cals.*
Av. of 3 periods.	4.65	7.5	200	0.84	238	73	1.15
With food:[1]							
10^h44^ma.m.....	5.36	10.4	219	.89	245	73	1.20
11 17 a.m.....	5.41	12.5	216	.91	237	69	1.17
12 05 p.m.....	5.20	7.9	225	.97	232	68	1.16
12 37 p.m.....	5.46	8.4	239	.99	242	70	1.22
1 06 p.m.....	5.46	9.3	228	.99	230	70	1.16
1 45 p.m.....	5.10	9.5	207	.87	238	75	1.16

[1]Subject drank dextrose and lemon juice in 325 c.c. of water at 10^h05^m a. m.

TABLE 133.—*B. M. K., December 30, 1912. Lying.* (Values per minute.)

Dextrose: Amount, 100 grams; energy, 374 cals.; from carbohydrates, 100 p. ct.

Time.	Ventilation (reduced).	Average respiration rate.	Carbon dioxide.	Respiratory quotient.	Oxygen.	Average pulse rate.	Heat (computed).
Without food:	*liters.*		*c.c.*		*c.c.*		*cals.*
Av. of 4 periods.	4.99	16.3	152	0.70	217	71	1.02
With food:[1]							
11^h12^ma.m.....	4.83	17.5	156	.67	233	79	1.09
11 53 a.m.....	5.50	17.4	173	.73	236	83	1.11
1 19 p.m.....	5.70	17.5	188	.77	243	82	1.16
2 00 p.m.....	5.57	17.7	181	.79	228	79	1.09
2 54 p.m.....	5.11	16.8	166	.76	219	72	1.04
3 47 p.m.....	5.06	17.8	154	.72	214	71	1.01

[1]Subject drank dextrose in 250 c.c. of water at 11^h02^m a. m.

TABLE 134.—*A. J. O., December 11, 1914. Lying.* (Values per minute.)

Dextrose: Amount, 100 grams; energy, 374 cals.; from carbohydrates, 100 p. ct.

Time.	Ventilation (reduced).	Average respiration rate.	Carbon dioxide.	Respiratory quotient.	Oxygen.	Average pulse rate.	Heat (computed).
Without food:	*liters.*		*c.c.*		*c.c.*		*cals.*
Av. of 3 periods.	6.96	22.1	220	0.87	253	61	1.24
With food:[1]							
10h29ma.m.....	7.12	21.3	234	.91	258	..	1.27
10 32 a.m.....	7.22	22.0	239	.85	280	..	1.36
10 35 a.m.....	6.77	21.6	223	.87	257	..	1.26
10 40 a.m.....	6.83	21.0	223	.87	258	..	1.26
10 45 a.m.....	6.97	21.0	234	.90	261	..	1.29
10 50 a.m.....	7.23	21.4	243	.91	267	..	1.32
11 05 a.m.....	7.71	21.9	269	.94	287	69	1.43
11 44 a.m.....	8.29	21.5	297	.96	308	66	1.54

[1]Subject drank mixture (about 300 c.c.) of dextrose and cereal coffee at 10h25m a. m. About 1 gram of the preparation per 200 c.c. was used for the cereal coffee.

TABLE 135.—*Dr. P. R., May 3, 1912. Lying.* (Values per minute.)

Dextrose: Amounts, 100 grams dextrose, juice of one lemon; energy, 385 cals.; from carbohydrates. 100 p. ct.

Time.	Ventilation (reduced).	Average respiration rate.	Carbon dioxide.	Respiratory quotient.	Oxygen.	Average pulse rate.	Heat (computed).
Without food:	*liters.*		*c.c.*		*c.c.*		*cals.*
Av. of 3 periods.	4.29	14.0	146	0.78	186	53	0.89
With food:[1]							
11h02ma.m.....	4.45	14.8	150	.76	198	53	.94
11 24 a.m.....	4.71	16.2	161	.83	194	55	.94
11 43 a.m.....	5.09	17.2	177	.91	194	57	.96
12 25 p.m.....	5.07	16.6	173	.86	202	56	.98
12 57 p.m.....	4.93	15.9	175	.87	202	58	.99
1 42 p.m.....	5.04	16.2	174	.87	201	59	.98
2 32 p.m.....	5.00	17.2	171	.89	192	57	.94
3 12 p.m.....	4.99	16.5	167	.90	186	57	.92

[1]Subject drank dextrose and lemon juice in 325 c.c. of water at 10h58m a. m.

TABLE 136.—*J. J. C., December 22, 1910. Sitting.* (Values per minute.)

Dextrose: Amounts, 75 grams dextrose, juice of half lemon; energy, 286 cals.; from carbohydrates, 100 p. ct.

Time.	Average respiration rate.	Carbon dioxide.	Respiratory quotient.	Oxygen.	Average pulse rate.	Heat (computed).
Without food:		*c.c.*		*c.c.*		*cals.*
Av. of 4 periods.	18	193	0.88	220	59	1.08
With food:[1]						
12h49mp.m.....	20	203	.84	242	62	1.17
1 16 p.m.....	19	221	.91	243	60	1.20
1 39 p.m.....	18	236	.93	254	60	1.26
2 09 p.m.....	17	232	...	...	59	1.24

[1]Subject drank dextrose and lemon juice in 150 c.c. of water at 12h41m p. m.

TABLE 137.—*J. J. C., December 28, 1910. Lying.* (Values per minute.)

Dextrose: Amounts, 75 grams dextrose, juice of one lemon; energy, 292 cals.; from carbohydrates, 100 p. ct.

Time.	Average respiration rate.	Carbon dioxide.	Respiratory quotient.	Oxygen.	Average pulse rate.	Heat (computed).
		c.c.		c.c.		cals.
Without food:						
Av. of 6 periods..	18	203	0.86	235	69	1.15
With food:[1]						
1h01mp.m.....	17	228	.93	244	71	1.21
1 41 p.m.....	16	230	.98	235	68	1.18
2 17 p.m.....	16	248	.98	253	71	1.27
3 00 p.m.....	18	217	.94	230	65	1.14
3 28 p.m.....	17	216	.94	231	68	1.15
4 31 p.m.....	18	214	.87	247	70	1.21
5 14 p.m.....	21	215	.80	270	75	1.30

[1]Subject drank dextrose and lemon juice in 150 c.c. of water at 12h25m p. m.

TABLE 138.—*V. G., December 23, 1910. Sitting.* (Values per minute.)

Dextrose: Amounts, 75 grams dextrose, juice of half lemon; energy, 286 cals.; from carbohydrates, 100 p. ct.

Time.	Average respiration rate.	Carbon dioxide.	Respiratory quotient.	Oxygen.	Average pulse rate.	Heat (computed).
		c.c.		c.c.		cals.
Without food:						
Av. of 3 periods..	18	208	0.89	233	60	1.14
With food:[1]						
12h25mp.m.....	19	201	.84	240	57	1.16
12 54 p.m.....	20	210	.88	239	56	1.17
1 22 p.m.....	20	232	.86	269	60	1.31
2 08 p.m.....	19	235	.93	254	63	1.26
2 37 p.m.....	17	229	.93	247	68	1.23
3 06 p.m.....	17	238	.96	249	67	1.24
4 00 p.m.....	20	219	.97	225	61	1.13

[1]Subject drank dextrose and lemon juice in 150 c.c. of water at 12h15m p. m.

TABLE 139.—*V. G., December 29, 1910. Lying.* (Values per minute.)

Dextrose: Amounts, 75 grams dextrose, juice of one lemon; energy, 292 cals.; from carbohydrates 100 p. ct.

Time.	Average respiration rate.	Carbon dioxide.	Respiratory quotient.	Oxygen.	Average pulse rate.	Heat (computed).
		c.c.		c.c.		cals.
Without food:						
Av. of 5 periods..	20	214	0.90	237	60	1.17
With food:[1]						
12h26mp.m.....	20	231	.91	253	64	1.25
1 05 p.m.....	21	236	.92	256	65	1.27
1 34 p.m.....	15	254	1.00	254	72	1.28
2 09 p.m.....	19	236	.95	249	66	1.24
2 49 p.m.....	20	249	1.00	250	65	1.26

[1]Subject drank dextrose and lemon juice in 150 c.c. of water at 12h15m p. m.

LEVULOSE EXPERIMENTS.

K. H. A., 8h29m a. m. to 1h33m p. m., May 18, 1912. 66.5 kilograms.—In first food period opened mouth once; in fourth food period pulse rate very irregular; possibly opened mouth in this period; adhesive plaster over mouth in succeeding periods. Nitrogen in urine per hour 7h55m a. m. to 1h55m p. m., 0.66 gram.

J. P. C., 8h35m a. m. to 5h07m p. m., April 3, 1911.—In second basal period rubbed eyes with hand, also moved arms and legs. Chilly during third basal period; two blankets used; moved feet a little; slight movements in fourth basal period. In second food period, quiet and sleepy; coughed once in third food period; lips found drawn away from mouthpiece. Nitrogen in urine per hour 7h45m a. m. to 12h25m p. m., 0.55 gram; 12h25m p. m. to 5h15mp. m., 0.30 gram.

L. E. E., 8h37m a. m. to 2h44m p. m., May 22, 1911. 59.4 kilograms.—Defecated between second and third food periods, also between fourth and fifth periods; cramps in stomach in fourth period. Nitrogen in urine per hour 7h45m a. m. to 11h20m a. m., 0.43 gram; 11h20m a. m. to 1 p. m., 0.30 gram; 1 p. m. to 3h10m p. m., 0.40 gram.

C. H. H., 8h45m a. m. to 3h21m p. m., May 16, 1911. 55.2 kilograms.—Very quiet during first basal and third food periods; in latter period was falling asleep as period ended; in fifth food period, moved slightly several times; difficult to keep feet still; flies annoyed him somewhat in seventh food period. Nitrogen in urine per hour 7 a. m. to 3h45m p. m., 0.46 gram.

H. L. H., 8h43m a. m. to 3h11m p. m., June 1, 1911. 60.5 kilograms.—In first basal period very quiet and awake. Between second and third food periods defecated and urinated; between third and fourth food periods, somewhat restless; between fourth and fifth food periods left room to defecate. Nitrogen in urine per hour 8 a. m. to 10h55m a. m., 0.71 gram; 10h55m a. m. to 3h25m p. m., 0.54 gram.

P. F. J., 8h45m a. m. to 2h08m p. m., May 22, 1912.—57.4 kilograms—In second food period some nausea. Nitrogen in urine per hour 7h30m a. m. to 2h26m p. m., 0.39 gram.

J. J. C., 8h52m a. m. to 5h14m p. m., December 31, 1910.—High-carbohydrate diet on preceding day. Wooden framework used to keep head in position during experiment. Asleep most of first and second basal periods and in the intermission between these periods; also asleep in the intermission between first and second food periods and during second and fifth food periods; in sixth food period sleepy but moved slightly several times; awake throughout eighth and ninth food periods. Nitrogen in urine per hour 7 a. m. to 5h25m p. m., 0.25 gram.

J. J. C., 3h06m p. m. to 5h07m p. m., January 4, 1911. 64.6 kilograms.—Awake throughout and quiet. Nitrogen in urine per hour 8 a. m. to 5h10m p. m., 0.37 gram.

TABLE 140.—*K. H. A., May 18, 1912. Lying.* (Values per minute.)

Levulose: Amounts, 100 grams levulose, juice of one lemon; energy, 384 cals.; from carbohydrates, 100 p. ct.

Time.	Ventilation (reduced).	Average respiration rate.	Carbon dioxide.	Respiratory quotient.	Oxygen.	Average pulse rate.	Heat (computed).
Without food:	*liters.*		*c.c.*		*c.c.*		*cals.*
Av. of 3 periods.	4.79	13.7	179	0.82	218	48	1.05
With food:[1]							
10^h15^ma.m.....	6.09	14.7	235	.94	249	44	1.24
10 50 a.m.....	5.98	14.5	236	1.00	236	47	1.19
11 25 a.m.....	6.11	14.4	231	.97	239	48	1.20
12 05 p.m.....	5.50	14.2	208	.92	226	48	1.12
12 45 p.m.....	5.38	14.7	196	.91	216	45	1.07
1 18 p.m.....	5.04	14.5	182	.86	212	48	1.03

[1]Subject drank levulose and lemon juice in 325 c.c. of water at 9^h55^m (?) a. m.

TABLE 141.—*J. P. C., April 3, 1911. Lying.* (Values per minute.)

Levulose: Amounts, 100 grams levulose, juice of half lemon; energy, 379 cals.; from carbohydrates, 100 p. ct.

Time.	Average respiration rate.	Carbon dioxide.	Respiratory quotient.	Oxygen.	Average pulse rate.	Heat (computed).
Without food:		*c.c.*		*c.c.*		*cals.*
Av. of 5 periods..	18	185	0.85	217	51	1.06
With food:[1]						
12^h05^mp.m.....	21	240	1.01	237	55	1.20
12 38 p.m.....	20	241	1.03	233	56	1.18
1 12 p.m.....	20	231	.98	236	58	1.19
1 40 p.m.....	20	246	1.00	247	59	1.25
3 15 p.m.....	19	209	.89	236	57	1.16
4 25 p.m.....	19	198	.90	221	55	1.09
4 52 p.m.....	20	199	.85	234	53	1.14

[1]Subject drank solution (345 c.c.) at 11^h43^m a. m.

TABLE 142.—*L. E. E., May 22, 1911. Lying.* (Values per minute.)

Levulose: Amounts, 100 grams levulose, juice of half lemon; energy, 379 cals.; from carbohydrates, 100 p. ct.

Time.	Average respiration rate.	Carbon dioxide.	Respiratory quotient.	Oxygen.	Average pulse rate.	Heat (computed).
Without food:		*c.c.*		*c.c.*		*cals.*
Av. of 3 periods..	12	190	0.77	248	60	1.18
With food:[1]						
10^h05^ma.m.....	14	245	.94	262	57	1.30
10 59 a.m.....	12	263	.98	269	60	1.35
11 53 a.m.....	15	245	.95	257	61	1.28
12 28 p.m.....	15	248	1.00	247	59	1.25
1 24 p.m.....	13	202	.89	227	57	1.12
1 57 p.m.....	14	189	.82	231	57	1.11
2 28 p.m.....	15	185	.76	245	54	1.16

[1]Subject drank solution (325 c.c.) at 9^h48^m a. m.

TABLE 143.—*C. H. H., May 16, 1911. Lying.* (Values per minute.)

Levulose: Amounts, 100 grams levulose, juice of half lemon; energy, 379 cals.; from carbohydrates, 100 p. ct.

Time.	Average respiration rate.	Carbon dioxide.	Respiratory quotient.	Oxygen.	Average pulse rate.	Heat (computed).
Without food:		*c.c.*		*c.c.*		*cals.*
Av. of 2 periods..	14	177	0.88	201	61	0.98
With food:[1]						
9^h58^m a.m.....	13	204	.93	220	59	1.09
10 32 a.m.....	14	216	.97	222	62	1.11
11 07 a.m.....	15	216	.97	222	64	1.11
11 44 a.m.....	13	214	.94	227	65	1.13
12 23 p.m.....	13	198	.90	219	64	1.08
1 10 p.m.....	15	221	.99	223	63	1.12
1 44 p.m.....	15	206	.94	218	63	1.08
2 34 p.m.....	14	176	.85	207	59	1.01
3 06 p.m.....	15	178	.86	206	60	1.00

[1]Subject drank solution (325 c.c.) at 9^h46^m a. m.

TABLE 144.—*H. L. H., June 1, 1911. Lying.* (Values per minute.)

Levulose: Amounts, 100 grams levulose, juice of half lemon; energy, 379 cals.; from carbohydrates, 100 p. ct.

Time.	Average respiration rate.	Carbon dioxide.	Respiratory quotient.	Oxygen.	Average pulse rate.	Heat (computed).
Without food:		*c.c.*		*c.c.*		*cals.*
Av. of 2 periods..	15	197	0.83	237	63	1.15
With food:[1]						
10^h29^m a.m.....	17	259	1.02	255	65	1.29
11 20 a.m.....	16	247	.98	251	66	1.26
12 04 p.m.....	14	249	1.00	250	65	1.26
12 40 p.m.....	16	222	.90	246	65	1.21
1 22 p.m.....	17	239	.96	248	66	1.24
2 14 p.m.....	20	211	.88	239	65	1.17
2 56 p.m.....	18	198	.82	242	61	1.17

[1]Subject drank solution (325 c.c.) at 9^h58^m a. m.

TABLE 145.—*P. F. J., May 22, 1912. Lying.* (Values per minute.)

Levulose: Amounts, 100 grams levulose, juice of one lemon; energy, 384 cals.; from carbohydrates, 100 p. ct.

Time.	Ventilation (reduced).	Average respiration rate.	Carbon dioxide.	Respiratory quotient.	Oxygen.	Average pulse rate.	Heat (computed).
Without food:	*liters.*		*c.c.*		*c.c.*		*cals.*
Av. of 3 periods.	4.89	8.6	206	0.91	226	72	1.12
With food:[1]							
10^h26^m a.m.....	6.65	16.4	245	1.07	229	64	1.16
10 55 a.m.....	6.64	12.9	263	1.11	238	71	1.20
11 32 a.m.....	6.33	11.7	253	1.03	246	80	1.24
12 25 p.m.....	5.65	10.4	246	1.00	245	74	1.24
1 03 p.m.....	6.01	10.0	237	.96	247	74	1.23
1 53 p.m.....	5.46	11.1	211	.93	226	70	1.12

[1]Subject drank levulose and lemon juice in 325 c.c. of water at 10^h10^m a. m.

TABLE 146.—*A. J. O., December 8, 1914. Lying.* (Values per minute.)

Levulose: Amount, 100 grams; energy, 373 cals.; from carbohydrates, 100 p. ct.

Time.	Ventilation (reduced).	Average respiration rate.	Carbon dioxide.	Respiratory quotient.	Oxygen.	Average pulse rate.	Heat (computed).
Without food:	*liters.*		*c.c.*		*c.c.*		*cals.*
Av. of 3 periods.	6.92	23.0	220	0.90	245	60	1.21
With food:[1]							
10^h20^m a.m.....	6.69	22.0	219	.96	229	..	1.14
10 23 a.m.....	7.59	21.3	262	1.07	244	..	1.23
10 26 a.m.....	7.06	19.5	250	1.09	230	..	1.16
10 30 a.m.....	7.44	19.1	264	1.07	246	..	1.24
10 35 a.m.....	7.66	19.7	275	1.10	249	..	1.26
10 40 a.m.....	7.69	20.0	272	1.05	258	..	1.30
10 51 a.m.....	8.53	21.5	304	1.09	280	59	1.41
11 36 a.m.....	8.37	22.5	273	.98	279	64	1.40

[1]Subject drank mixture (about 300 c.c.) of levulose and cereal coffee at 10^h15^m a. m. About 1 gram of the preparation per 200 c.c. was used for the cereal coffee.

TABLE 147.—*J. J. C., December 31, 1910. Lying.* (Values per minute.)

Levulose: Amount, 75 grams.; energy, 280 cals.; from carbohydrates, 100 p. ct.

Time.	Average respiration rate.	Carbon dioxide.	Respiratory quotient.	Oxygen.	Average pulse rate.	Heat (computed).
Without food:		*c.c.*		*c.c.*		*cals.*
Av. of 3 periods..	17	200	0.91	220	65	1.09
With food:[1]						
10^h42^m a.m.....	17	262	1.10	239	62	1.21
11 10 a.m.....	18	253	1.05	240	70	1.21
11 41 a.m.....	18	267	1.04	256	69	1.29
12 17 p.m.....	17	243	.99	246	74	1.24
12 49 p.m.....	17	232	.96	241	75	1.20
1 19 p.m.....	16	228	.95	240	69	1.20
1 50 p.m.....	16	215	.93	230	67	1.14
2 33 p.m.....	18	221	.95	233	72	1.16
4 32 p.m.....	19	220	.98	225	66	1.13
5 00 p.m.....	20	211	.86	246	67	1.20

[1]Subject took levulose at 10^h27^m a. m.

TABLE 148.—*J. J. C., January 4, 1911. Lying.* (Values per minute.)

Levulose: Amounts, 75 grams levulose, juice of one lemon; energy, 291 cals.; from carbohydrates, 100 p. ct.

Time.	Average respiration rate.	Carbon dioxide.	Respiratory quotient.	Oxygen.	Average pulse rate.	Heat (computed).
Without food:		*c.c.*		*c.c.*		*cals.*
Av. of 2 periods..	21	213	0.89	240	65	1.18
With food:[1]						
4^h04^m p.m.....	20	270	1.04	260	71	1.31
4 30 p.m.....	20	276	1.05	262	64	1.32
4 52 p.m.....	20	272	1.01	269	69	1.36

[1]Subject drank levulose and lemon juice in 150 c.c. of water at 3^h52^m p. m.

SUCROSE EXPERIMENTS.

H. H. A., 7h42m a. m. to 12h56m p. m., January 2, 1912.[1] 61.2 kilograms.—Urinated and defecated between fifth and sixth food periods, resting about 15 minutes afterward. Nitrogen in urine per hour 6h45m a. m. to 10h30m a. m., 0.33 gram; 10h30m a. m. to 11h50m a. m., 0.25 gram.

L. E. E., 8h44m a. m. to 3h19m p. m., May 15, 1911. 60.3 kilograms.—Quiet throughout experiment with occasional slight movements; asleep in last two or three minutes of fourth food period. Defecated at 12h55m p. m. Nitrogen in urine per hour 8 a. m. to 10h05m a. m., 0.61 gram; 10h05m a. m. to 12h55m p. m., 0.48 gram; 12h55m p. m. to 3h30m p. m., 0.30 gram.

A. F. G., 8h38m a. m. to 2h05m p. m., May 20, 1911. 53.9 kilograms.—Lay down on couch at 8 a. m. after drinking a glass of water. Quiet in first and second basal periods; in first food period somewhat nervous and apprehensive. In third food period, there seemed to be a leakage of air, but it was not located. Nitrogen in urine per hour 6h30m a. m. to 10h56m a. m., 0.36 gram; 10h56m a. m. to 2h30m p. m., 0.48 gram.

C. H. H., 8h42m a. m. to 2h25m p. m., May 10, 1911. 55.5 kilograms.—Awake and quiet throughout experiment; much more wide awake in last period than in preceding. Found it difficult to take full amount of sucrose. Nitrogen in urine per hour 7 a. m. to 12h12m p. m., 0.34 gram; 12h12m p. m. to 2h40m p. m. 0.68 gram.

H. L. H., 8h31m a. m. to 2h21m p. m., May 17, 1911. 59.9 kilograms.—Quiet and awake throughout experiment; in first basal period had difficulty in breathing due to a cold; larger nosepieces were given him before second basal period, which enabled him to breathe more easily, although nosepieces gave him more or less discomfort owing to soreness of nostrils due to cold. In second food period pulse rate high, probably due to fact that visitors were expected. Nitrogen in urine per hour 10h52m a. m. to 2h52m p. m., 0.43 gram.

Professor C., 8h46m a. m. to 11h35m a. m., November 20, 1909. 83.0 kilograms.—First food period only 10 minutes long. Defecated at 10h15m a. m. Nitrogen in urine per hour 10h15m a. m. to 11h35m a. m., 0.79 gram.

Professor C., 8h37m a m. to 2h42m p. m., November 22, 1909. 83.0 kilograms.—First food period 10 minutes long; intermission between basal and food periods, 3 hours and 51 minutes. During intermission went on roof of laboratory; sat there from 9h45m a. m. to 11h15m a. m., without coat and part of time without vest; temperature of air 6.9° C.; a little rain; sugar and coffee taken after exposure to cold. Time between return from roof and beginning of first food period 2 hours and 10 minutes; lay on couch much of this time and a series of three observations were made not included in this record. Between first and second food periods and in third food period, nervous and restless. Nitrogen in urine per hour 7h40m a. m. to 11h15m a. m., 0.65 gram.

A. J. O., 9h07m a. m. to 11h57m a. m., December 29, 1914. 70.0 kilograms.—Length of periods irregular, ranging from 3 to 10 minutes. Nitrogen in urine per hour, 8 a. m. to 12h20m p. m., 0.69 gram.

J. J. C., 1h53m p. m. to 5h28m p. m., November 22, 1910. 64.3 kilograms.—high-carbohydrate diet on preceding day. Quiet throughout basal periods, very quiet in second basal period; slept between second and third periods and in third basal period was kept awake with difficulty. In third basal period, lower lip dropped sufficiently to show the teeth; adhesive plaster was used over mouth in succeeding periods. So sleepy in last basal and in all food periods that constant attention of observer was required to keep him awake;

[1]Benedict and Joslin, Carnegie Inst. Wash. Pub. No. 176, 1912, p. 130.

in spite of all efforts, went to sleep in last period. Nitrogen in urine per hour 8^h15^m a. m. to 4^h13^m p. m., 0.38 gram; 4^h13^m p. m. to 5^h45^m p. m., 0.29 gram.

J. J. C., 9^h01^m a. m. to 4^h20^m p. m., December 6, 1910. 63.3 kilograms.—Low-carbohydrate diet on preceding day. Very quiet in basal periods, most of time asleep; asleep at end of both first and second food periods; during third period adhesive plaster became loosened while subject was asleep; he doubtless inhaled air; in seventh period, slept most of time but was constantly awakened by observer. To prevent possible leakage of air during sleep, rubber bandage used around head and over upper lip in eighth and ninth food periods, but even with this device mouth apparently opened once in latter period; as bandage caused discomfort, it was removed and only the adhesive plaster alone used thereafter. Awake in last period. Nitrogen in urine per hour 8^h25^m a. m. to 4^h40^m p. m., 0.48 gram.

J. J. C., 8^h49^m a. m. to 3^h02^m p. m., December 8, 1910. 63.5 kilograms.—High-carbohydrate diet on preceding day. Wooden head-rest used. Subject slept between first and second basal periods and continued to be very sleepy, requiring entire attention of one observer to keep him awake. In first food period not so sleepy as previously, but observer spoke to him frequently to make sure that he was awake; slight activity in second food period; several movements in fourth food period; asleep most of fifth and sixth periods, although frequently awakened. In seventh and eighth periods fell asleep; when awakened made slight movements; in last period drew deep breath. Nitrogen in urine per hour 7^h30^m a. m. to 3^h14^m p. m., 0.39 gram.

J. J. C., 8^h48^m a. m. to 5^h21^m p. m., December 20, 1910. 64.7 kilograms.—Subject sat in chair. High-carbohydrate diet on preceding day. Some sleep between second and third basal periods; coughed once in third basal period with possibility of slight loss of air; left nosepiece loosened in fourth period; possible leak in left nosepiece in fourth food period; a number of deep breaths in fifth food period; very quiet in eighth and ninth periods, but no tendency toward sleep. Nitrogen in urine per hour 7^h10^m a. m. to 5^h23^m p. m., 0.20 gram.

V. G., 8^h17^m a. m. to 2^h53^m p. m., November 18, 1910. 53.9 kilograms.—Two pillows and wooden head-rest. Very quiet during first five basal periods, at times showing tendency to go to sleep; fell asleep once and slept between periods. Quiet in last two basal periods. Left room for urinating before taking sucrose. In last food period found it difficult to breathe; several very deep respirations. Nitrogen in urine per hour 7^h50^m a. m. to 1^h15^m p. m., 0.49 gram; 1^h15^m p. m. to 3^h20^m p. m., 0.41 gram.

V. G., 8^h35^m a. m. to 4^h47^m p. m., November 30, 1910. 53.9 kilograms.—High-carbohydrate diet day preceding. Slept most of first basal period and also throughout second and third basal periods; sound asleep in third food period and slept during fifth food period. Awake most of sixth food period, but slept again part of seventh food period. Apparatus tested in intermission of one and one-half hours between seventh and eighth food periods. Some nausea at this time. Defecated at 3^h37^m p. m. Nitrogen in urine per hour 7 a. m. to 3^h37^m p. m., 0.31 gram; 3^h37^m p. m. to 5^h19^m p. m., 0.24 gram.

V. G., 8^h21^m a. m. to 5^h46^m p. m., November 21, 1910. 53.9 kilograms.—First and second basal periods very quiet; very sleepy in third basal period and after several efforts to keep him awake was allowed to sleep. Slight movement in sixth period; asleep most of eighth period and very quiet. In food periods, very quiet, coughing once in fourth food period. Nitrogen in urine per hour 6^h45^m a. m. to 3^h05^m p. m., 0.18 gram; 3^h05^m p. m. to 5^h50^m p. m., 0.20 gram.

TABLE 149.—*H. H. A., January 2, 1912. Lying.* (Values per minute.)

Sucrose: Amounts, 100 grams sucrose, juice of one lemon; energy, 408 cals.; from carbohydrates, 100 p. ct.

Time.	Ventilation (reduced).	Average respiration rate.	Carbon dioxide.	Respiratory quotient.	Oxygen.	Average pulse rate.	Heat (computed).
Without food:	*liters.*		*c.c.*		*c.c.*		*cals.*
Av. of 3 periods	4.29	12	153	0.72	213	66	1.00
With food:[1]							
9h22ma.m.	5.17	11	209	.87	239	73	1.17
9 45 a.m.	6.73	15	242	1.05	230	79	1.16
10 14 a.m.	6.86	15	238	.98	243	76	1.22
11 05 a.m.	6.85	15	229	.93	245	80	1.22
11 34 a.m.	5.76	14	201	.84	239	85	1.16
12 41 p.m.	4.62	12	173	.76	228	80	1.08

[1]Subject drank sucrose and lemon juice in 400 c.c. of water at 9h12m a. m.

TABLE 150.—*L. E. E., May 15, 1911. Lying.* (Values per minute.)

Sucrose: Amounts, 100 grams sucrose, juice of half lemon; energy, 402 cals.; from carbohydrates, 100 p. ct.

Time.	Average respiration rate.	Carbon dioxide.	Respiratory quotient.	Oxygen.	Average pulse rate.	Heat (computed).
Without food:		*c.c.*		*c.c.*		*cals.*
Av. of 3 periods	9	189	0.78	243	60	1.16
With food:[1]						
10h17ma.m.	14	235	.93	254	58	1.26
10 47 a.m.	12	280	1.00	280	64	1.41
11 30 a.m.	14	272	.98	278	64	1.40
12 15 p.m.	14	219	.93	236	61	1.17
1 17 p.m.	10	204	.87	234	56	1.14
2 07 p.m.	9	207	.83	248	55	1.20
3 03 p.m.	8	196	.76	259	55	1.23

[1]Subject drank solution (325 c.c.) at 9h56m a. m.

TABLE 151.—*A. F. G., May 20, 1911. Lying.* (Values per minute.)

Sucrose: Amounts, 100 grams sucrose, juice of half lemon; energy, 402 cals.; from carbohydrates, 100 p. ct.

Time.	Average respiration rate.	Carbon dioxide.	Respiratory quotient.	Oxygen.	Average pulse rate.	Heat (computed).
Without food:		*c.c.*		*c.c.*		*cals.*
Av. of 3 periods	16	178	0.86	207	61	1.01
With food:[1]						
10h29ma.m.	17	227	.95	238	65	1.19
11 19 a.m.	19	254	.97	263	71	1.32
11 54 a.m.	15	223	...	...	70	1.17
12 33 p.m.	16	197	.93	212	68	1.05
1 14 p.m.	18	181	.83	218	67	1.05
1 50 p.m.	17	178	.82	216	65	1.04

[1]Subject drank solution (325 c.c.) at 10h13m a. m.

TABLE 152.—*C. H. H., May 10, 1911. Lying.* (Values per minute.)

Sucrose: Amounts, 100 grams sucrose, juice of half lemon; energy, 402 cals.; from carbohydrates, 100 p. ct.

Time.	Average respiration rate.	Carbon dioxide.	Respiratory quotient.	Oxygen.	Average pulse rate.	Heat (computed).
Without food:		*c.c.*		*c.c.*		*cals.*
Av. of 3 periods..	14	171	0.86	200	56	0.98
With food:[1]						
10^h35^m a.m.....	14	238	.98	244	59	1.23
11 01 a.m.....	13	214	.90	237	62	1.17
11 35 a.m.....	14	217	.96	226	64	1.13
12 22 p.m.....	14	225	.99	228	64	1.15
12 59 p.m.....	13	186	.90	206	59	1.01
1 32 p.m.....	13	167	.87	193	57	.94
2 10 p.m.....	15	184	.84	218	59	1.06

[1]Subject drank solution (325 c.c.) at 10^h11^m a. m.

TABLE 153.—*H. L. H., May 17, 1911. Lying.* (Values per minute.)

Sucrose: Amounts, 100 grams sucrose, juice of half lemon; energy, 402 cals.; from carbohydrates, 100 p. ct.

Time.	Average respiration rate.	Carbon dioxide.	Respiratory quotient.	Oxygen.	Average pulse rate.	Heat (computed).
Without food:		*c.c.*		*c.c.*		*cals.*
Av. of 3 periods..	14	191	0.82	232	64	1.12
With food:[1]						
10^h30^m a.m.....	15	264	.99	268	65	1.35
11 18 a.m.....	14	244	.94	259	75	1.29
12 49 p.m.....	15	213	.96	222	67	1.11
1 27 p.m.....	16	193	.83	233	63	1.13
2 06 p.m.....	15	203	.78	259	67	1.24

[1]Subject drank solution (325 c.c.) at 9^h57^m a. m.

TABLE 154.—*Prof. C., November 20, 1909. Lying.* (Values per minute.)

Sucrose and black coffee:

Amounts, 100 grams sucrose, 200 grams coffee; nitrogen, 0.16 gram; total energy, 424 cals.
Fuel value: Total, 422 cals.; from carbohydrates, 99 p. ct.; from protein, 1 p. ct.

Time.	Average respiration rate.	Carbon dioxide.	Respiratory quotient.	Oxygen.	Average pulse rate.	Heat (computed).
Without food:		*c.c.*		*c.c.*		*cals.*
Av. of 4 periods..	14	203	0.86	236	63	1.15
With food:[1]						
10^h36^m a.m.....	15	306	1.07	286	71	1.44
10 57 a.m.....	14	297	1.06	279	67	1.41
11 20 a.m.....	15	271	.98	277	68	1.39

[1]Subject drank sucrose and coffee at 10^h31^m a. m.

TABLE 155.—*Prof. C., November 22, 1909. Lying.* (Values per minute.)

Sucrose and black coffee:

Amounts, 100 grams sucrose, 200 grams coffee; nitrogen, 0.16 gram; total energy, 424 cals.
Fuel value: Total, 422 cals.; from carbohydrates, 99 p. ct.; from protein, 1 p. ct.

Time.	Average respiration rate.	Carbon dioxide.	Respiratory quotient.	Oxygen.	Average pulse rate.	Heat (computed).
Without food:		*c.c.*		*c.c.*		*cals.*
Av. of 3 periods..	14	213	0.88	241	65	1.18
With food:[1]						
1^h25^m p.m.....	14	302	1.10	275	55	1.39
1 41 p.m.....	15	275	.98	281	57	1.41
2 04 p.m.....	14	249	.91	273	57	1.35
2 27 p.m.....	16	242	.90	268	58	1.32

[1]Subject drank sucrose and coffee at about 1 p. m.

TABLE 156.—*A. J. O., December 29, 1914. Lying.* (Values per minute.)

Sucrose: Amount, 100 grams; energy, 396 cals.; from carbohydrates, 100 p. ct.

Time.	Ventilation (reduced).	Average respiration rate.	Carbon dioxide.	Respiratory quotient.	Oxygen.	Average pulse rate.	Heat (computed).
Without food:	*liters.*		*c.c.*		*c.c.*		*cals.*
Av. of 3 periods.	6.36	18.3	224	0.88	254	60	1.24
With food:[1]							
10^h34^m a.m.....	7.90	19.0	299	1.03	290	..	1.46
10 37 a.m.....	7.74	17.8	300	1.08	277	..	1.40
10 41 a.m.....	8.68	19.2	329	1.12	293	..	1.48
10 46 a.m.....	8.65	19.4	337	1.14	294	..	1.48
10 51 a.m.....	8.88	19.0	347	1.14	305	..	1.54
10 56 a.m.....	8.65	17.2	345	1.11	311	..	1.57
11 15 a.m.....	8.02	17.3	313	1.00	314	67	1.58
11 49 a.m.....	8.30	20.0	314	1.03	305	68	1.54

[1]Subject drank mixture (about 300 c.c.) of sucrose and cereal coffee at 10^h27^m a. m. About 1 gram of the preparation per 200 c.c. was used for the cereal coffee.

TABLE 157.—*J. J. C., November 22, 1910. Lying.* (Values per minute.)

Sucrose: Amounts, 75 grams sucrose, juice of half lemon; energy, 303 cals.; from carbohydrates, 100 p. ct.

Time.	Average respiration rate.	Carbon dioxide.	Respiratory quotient.	Oxygen.	Average pulse rate.	Heat (computed).
Without food:		*c.c.*		*c.c.*		*cals.*
Av. of 4 periods..	16	202	0.87	231	63	1.13
With food:[1]						
4^h20^m p.m.....	17	239	.97	247	60	1.24
4 45 p.m.....	17	270	1.03	262	61	1.32
5 13 p.m.....	16	251	1.00	252	65	1.27

[1]Subject drank sucrose and lemon juice in 150 c.c. of water at 4^h17^m p. m.

TABLE 158.—*J. J. C., December 6, 1910. Lying.* (Values per minute.)

Sucrose: Amounts, 75 grams sucrose, juice of one lemon; energy, 309 cals.; from carbohydrates, 100 p. ct.

Time.	Average respiration rate.	Carbon dioxide.	Respiratory quotient.	Oxygen.	Average pulse rate.	Heat (computed).
		c.c.		*c.c.*		*cals.*
Without food:						
Av. of 3 periods..	16	190	0.80	238	64	1.14
With food:[1]						
10^h51^m a.m.....	17	205	.84	243	63	1.18
11 20 a.m.....	16	257	.95	270	66	1.35
11 55 a.m.....	17	248	....	...	71	1.30
12 35 p.m.....	15	223	.87	255	72	1.25
1 11 p.m.....	16	222	.92	242	69	1.20
1 44 p.m.....	15	216	.88	245	70	1.20
2 18 p.m.....	14	212	.87	244	66	1.19
2 51 p.m.....	15	207	.87	238	68	1.16
3 28 p.m.....	17	208	....	...	70	1.18
4 05 p.m.....	20	206	.84	244	68	1.18

[1]Subject drank sucrose and lemon juice in 150 c.c. of water at 10^h42^m a. m.

TABLE 159.—*J. J. C., December 8, 1910. Lying.* (Values per minute.)

Sucrose: Amounts, 75 grams sucrose, juice of one lemon; energy, 309 cals.; from carbohydrates, 100 p. ct.

Time.	Average respiration rate.	Carbon dioxide.	Respiratory quotient.	Oxygen.	Average pulse rate.	Heat (computed).
		c.c.		*c.c.*		*cals.*
Without food:						
Av. of 4 periods..	17	202	0.85	237	70	1.15
With food:[1]						
11^h04^m a.m.....	18	246	1.04	237	66	1.20
11 37 a.m.....	17	264	1.01	261	68	1.32
12 11 p.m.....	16	254	1.00	253	70	1.28
12 41 p.m.....	15	228	....	...	71	1.15
1 08 p.m.....	18	235	1.01	232	74	1.17
1 41 p.m.....	18	213	.93	228	63	1.13
2 17 p.m.....	17	204	.90	227	65	1.12
2 47 p.m.....	18	210	.89	236	63	1.16

[1]Subject drank sucrose and lemon juice in 150 c.c. of water at 10^h53^m a. m.

TABLE 160.—*J. J. C., December 20, 1910. Sitting.* (Values per minute.)

Sucrose: Amounts, 75 grams sucrose, juice of one lemon; energy, 309 cals.; from carbohydrates, 100 p. ct.

Time.	Average respiration rate.	Carbon dioxide.	Respiratory quotient.	Oxygen.	Average pulse rate.	Heat (computed).
Without food:		*c.c.*		*c.c.*		*cals.*
Av. of 5 periods..	19	196	0.85	231	67	1.12
With food:[1]						
11h27m a.m.....	19	226	.91	249	65	1.23
11 52 a.m.....	20	259	1.02	253	63	1.28
12 24 p.m.....	20	250	1.01	248	65	1.25
12 51 p.m.....	17	233	.95	245	65	1.22
1 25 p.m.....	20	223	.92	243	72	1.20
1 53 p.m.....	17	204	.89	229	69	1.12
2 19 p.m.....	16	206	.92	224	61	1.11
4 45 p.m.....	21	209	.89	234	66	1.15
5 06 p.m.....	21	203	.88	231	65	1.13

[1]Subject drank sucrose and lemon juice in 150 c.c. of water at 11h16m a. m.

TABLE 161.—*V. G., November 18, 1910. Lying.* (Values per minute.)

Sucrose: Amounts, 75 grams sucrose, juice of one lemon; energy, 309 cals.; from carbohydrates, 100 p. ct.

Time.	Average respiration rate.	Carbon dioxide.	Respiratory quotient.	Oxygen.	Average pulse rate.	Heat (computed).
Without food:		*c.c.*		*c.c.*		*cals.*
Av. of 7 periods.	20	203	0.83	244	63	1.18
With food:[1]						
1h30mp.m.....	22	216	.83	260	..	1.26
2 03 p.m.....	22	245	.91	270	70	1.33
2 38 p.m.....	18	225	.89	253	73	1.24

[1]Subject drank sucrose and lemon juice in 150 c.c. of water at 1h19m p. m.

TABLE 162.—*V. G., November 30, 1910. Lying.* (Values per minute.)

Sucrose: Amounts, 75 grams sucrose, juice of one lemon; energy, 309 cals.; from carbohydrates, 100 p. ct.

Time.	Average respiration rate.	Carbon dioxide.	Respiratory quotient.	Oxygen.	Average pulse rate.	Heat (computed).
Without food:		*c.c.*		*c.c.*		*cals.*
Av. of 4 periods..	19	190	0.84	226	56	1.10
With food:[1]						
11h15ma.m.....	21	227	.94	242	63	1.20
11 50 a.m.....	21	216	.93	233	64	1.16
12 21 p.m.....	21	241	1.01	239	61	1.21
12 58 p.m.....	19	245	.97	252	63	1.26
1 31 p.m.....	20	213	.94	227	65	1.13
2 03 p.m.....	17	238	.98	244	68	1.23
2 45 p.m.....	20	206	.91	227	65	1.12
4 32 p.m.....	20	221	.93	237	57	1.18

[1]Subject drank sucrose and lemon juice in 150 c.c. of water at 11h07m a. m.

TABLE 163.—*V. G., November 21, 1910. Lying.* (Values per minute.)

Sucrose: Amounts, 73 grams sucrose, juice of half lemon; energy, 295 cals.; from carbohydrates, 100 p. ct.

Time.	Average respiration rate.	Carbon dioxide.	Respiratory quotient.	Oxygen.	Average pulse rate.	Heat (computed).
Without food:		*c.c.*		*c.c.*		*cals.*
Av. of 9 periods..	21	200	0.84	238	65	1.15
With food:[1]						
3^h17^m p.m.....	19	207	.84	245	63	1.19
3 50 p.m.....	23	264	1.06	250	64	1.26
4 22 p.m.....	20	232	.96	242	71	1.21
5 08 p.m.....	18	235	.94	249	73	1.24
5 32 p.m.....	21	238	.95	250	73	1.25

[1]Subject drank sucrose and lemon juice in 150 c.c. of water at 3^h10^m p. m.

LACTOSE EXPERIMENTS.

K. H. A., 8^h45^m a. m. to 1^h07^m p. m., May 23, 1912. 65.8 kilograms.—At 10^h30^m p. m. on preceding day took corn breakfast food (dry) with milk and sugar, one cup coffee with milk and teaspoonful sugar, and one ham sandwich. Drowsy in second food period; complained of pain in stomach in fifth food period, but was better in sixth food period.

L. E. E., 8^h48^m a. m. to 3^h15^m p. m., June 5, 1911. 59.6 kilograms.—Slept a moment or two in second basal period and a little in second food period, also in intermissions between first and second food periods and between second and third food periods; somewhat restless between fifth and sixth food periods. Nosepieces out of position and leaked near end of sixth food period. In seventh food period found breathing difficult, felt faint, and breathed very deeply, as absorber failed to absorb carbon dioxide readily. Nitrogen in urine per hour 8 a. m. to 10^h30^m a. m., 0.53 gram; 10^h30^m a. m. to 2^h25^m p. m., 0.44 gram.

C. H. H., 9^h03^m a. m. to 3^h34^m p. m., May 23, 1911. 54.9 kilograms.—Awake and very quiet, remaining practically in same position throughout experiment; in last food period more wide awake than in previous periods. Nitrogen in urine per hour 7^h10^m a. m. to 12^h44^m p. m., 0.38 gram; 12^h44^m p. m. to 3^h50^m p. m., 0.42 gram.

H. L. H., 8^h51^m a. m. to 3^h24^m p. m., June 7, 1911. 60.4 kilograms.—Moved feet in first period; very restless between first and second periods; flies troubled him in second basal period; very quiet in fifth and sixth food periods; flies again troubled him in seventh food period. Nitrogen in urine per hour 6^h35^m a. m. to 11^h36^m a. m., 0.44 gram; 11^h36^m a. m. to 2^h35^m p. m., 0.39 gram.

A. J. O., 8^h58^m a. m. to 1^h11^m p. m., January 4, 1915. 70.1 kilograms.—Length of periods irregular, ranging from 3 to 12 minutes. Nitrogen in urine per hour, 7^h50^m a. m. to 10^h20^m a. m., 0.44 gram; 10^h20^m a. m. to 1^h15^m p. m., 0.57 gram.

TABLE 164.—*K. H. A., May 23, 1912. Lying.* (Values per minute.)

Lactose: Amounts, 100 grams lactose, juice of one lemon; energy, 385 cals.; from carbohydrates, 100 p. ct.

Time.	Ventilation (reduced).	Average respiration rate.	Carbon dioxide.	Respiratory quotient.	Oxygen.	Average pulse rate.	Heat (computed).
Without food:	*liters.*		*c.c.*		*c.c.*		*cals.*
Av. of 3 periods.	5.36	13.1	196	0.81	243	51	1.17
With food:[1]							
10^h07^m a.m.....	5.44	14.0	199	.79	253	47	1.21
10 42 a.m.....	5.33	14.1	199	....	...	46	1.21
11 15 a.m.....	6.59	15.5	240	.95	253	50	1.26
11 47 a.m.....	6.90	17.6	236	.96	245	59	1.22
12 18 p.m.....	6.65	15.8	237	.95	250	59	1.25
12 52 p.m.....	6.45	15.2	236	.99	239	61	1.20

[1]Subject drank lactose and lemon juice in 325 c.c. of water at 9^h54^m a. m.

TABLE 165.—*L. E. E., June 5, 1911. Lying.* (Values per minute.)

Lactose: Amounts, 100 grams lactose, juice of two-thirds lemon; energy, 381 cals.; from carbohydrates, 100 p. ct.

Time.	Average respiration rate.	Carbon dioxide.	Respiratory quotient.	Oxygen.	Average pulse rate.	Heat (computed).
Without food:		*c.c.*		*c.c.*		*cals.*
Av. of 3 periods..	13	189	0.83	229	58	1.11
With food:[1]						
10^h44^m a.m.....	16	237	.93	256	54	1.27
11 14 a.m.....	16	232	.94	248	55	1.23
11 48 a.m.....	16	228	.92	248	57	1.23
12 43 p.m.....	12	236	.96	247	57	1.23
1 13 p.m.....	15	214	.92	233	59	1.15
1 56 p.m.....	13	193	....	...	57	1.10
3 00 p.m.....	11	...	....	235	55	1.14

[1]Subject drank solution (325 c.c.) at 10^h06^m a. m.

TABLE 166.—*C. H. H., May 23, 1911. Lying.* (Values per minute.)

Lactose: Amounts, 100 grams lactose, juice of half lemon; energy, 379 cals.; from carbohydrates, 100 p. ct.

Time.	Average respiration rate.	Carbon dioxide.	Respiratory quotient.	Oxygen.	Average pulse rate.	Heat (computed).
Without food:		*c.c.*		*c.c.*		*cals.*
Av. of 2 periods..	15	167	0.83	202	59	0.98
With food:[1]						
10^h17^m a.m.....	15	184	.79	233	58	1.12
10 46 a.m.....	15	184	.84	220	57	1.07
11 20 a.m.....	15	189	.90	211	58	1.04
11 52 a.m.....	15	199	.88	227	58	1.11
12 25 p.m.....	16	206	.89	232	60	1.14
1 05 p.m.....	14	183	.86	213	57	1.04
1 40 p.m.....	15	178	.84	212	56	1.03
2 14 p.m.....	15	163	.81	202	54	.97
3 17 p.m.....	15	172	.73	235	56	1.11

[1]Subject drank solution (325 c.c.) at 10 a. m.

TABLE 167.—*H. L. H., June 7, 1911. Lying.* (Values per minute.)

Lactose: Amounts, 100 grams lactose, juice of half lemon; energy, 379 cals.; from carbohydrates, 100 p. ct.

Time.	Average respiration rate.	Carbon dioxide.	Respiratory quotient.	Oxygen.	Average pulse rate.	Heat (computed).
Without food:		*c.c.*		*c.c.*		*cals.*
Av. of 2 periods..	15	191	0.82	232	59	1.12
With food:[1]						
10^h18^ma.m.....	16	207	.84	247	61	1.20
11 06 a.m.....	16	236	.96	247	64	1.23
11 53 a.m.....	15	228	.93	246	63	1.22
12 45 p.m.....	16	222	.90	247	57	1.22
1 16 p.m.....	16	201	.88	228	59	1.12
2 02 p.m.....	16	194	.81	239	56	1.15
3 09 p.m.....	15	196	.79	248	58	1.19

[1]Subject drank solution (325 c.c.) at 9^h53^m a. m.

TABLE 168.—*A. J. O., January 4, 1915. Lying.* (Values per minute.)

Lactose: Amount, 100 grams; energy, 374 cals.; from carbohydrates, 100 p. ct.

Time.	Ventilation (reduced).	Average respiration rate.	Carbon dioxide.	Respiratory quotient.	Oxygen.	Average pulse rate.	Heat (computed).
Without food:	*liters.*		*c.c.*		*c.c.*		*cals.*
Av. of 10 periods.	6.20	19.3	211	0.84	251	60	1.22
With food:[1]							
11^h43^ma.m.....	7.33	21.0	246	.88	281	..	1.38
11 46 a.m.....	7.18	21.0	236	.88	267	..	1.31
11 49 a.m.....	7.00	20.0	240	.90	267	..	1.31
11 53 a.m.....	7.27	20.6	251	.94	268	..	1.33
11 58 a.m.....	7.52	18.6	276	1.01	272	..	1.37
12 03 p.m.....	7.82	20.4	279	1.01	275	..	1.39
12 20 p.m.....	7.95	19.2	300	1.01	297	59	1.50
1 02 p.m.....	7.82	20.6	274	.95	288	61	1.44

[1]Subject drank mixture (about 300 c.c.) of lactose and cereal coffee at 11^h39^m a. m. About 1 gram of the preparation per 200 c.c. was used for the cereal coffee.

GENERAL DISCUSSION OF RESPIRATION EXPERIMENTS WITH CARBOHYDRATES.

An inspection of tables 126 to 168 shows that the typical picture of a marked increase in the carbon-dioxide production appears in practically every case. The increment in the oxygen consumption, although not so large as that for the carbon-dioxide production, also appears in most of the experiments. Naturally the values for the heat production, computed from the gaseous exchange, show corresponding increments. The increase in the carbon-dioxide production is paralleled by a marked rise in the respiratory quotient which, in a large number of periods, exceeds unity. This is in harmony with the results obtained in the calorimeter experiments, for although it was not feasible to discuss the respiratory quotients for those experiments, since the basal

respiratory quotients for the same day were not obtained in many cases, we may note that most of the quotients after the ingestion of carbohydrate showed a value of 0.90 or above. Since the average respiratory quotient of normal man in the post-absorptive condition is not far from 0.83, it is obvious that these quotients above 0.90 substantiate the general observation that the respiratory quotient after carbohydrate ingestion is usually decidedly increased.

In the computation of the heat production from the oxygen consumption and the respiratory quotient, a difficulty is immediately encountered in the fact that the respiratory quotient is frequently over 1, especially the non-protein respiratory quotient. Experimental evidence as to the calorific value of oxygen and carbon dioxide under these conditions is much needed. An investigation of this problem is now in progress in this laboratory; pending its completion we have assumed, in common with other investigators, that when the quotient is above 1, the calorific values of carbon dioxide and oxygen are the same as those when the quotient is 1. The computations of the heat production were based entirely upon the oxygen consumption, since the carbon-dioxide excretion is greatly increased as a result of intermediary metabolism, with a possible splitting off of carbon dioxide accompanied by only minor increases in the production of heat.

MAXIMUM EFFECT ON METABOLISM OF CARBOHYDRATE INGESTION (INDIRECT CALORIMETRY).

We have reason to believe that not only the different sugars but also the different amounts of sugars vary somewhat in regard to the actual height to which the metabolism may be increased and the time when the maximum metabolism appears. It is important, therefore, to determine as accurately as possible both of these factors. In the calorimeter experiments it was found that the maximum heat production occurred some time during the first or second hour. Since in the respiration experiments observations are made every 15 or 20 minutes, it is possible to determine with considerable accuracy when the maximum or "peak" effect of carbohydrate ingestion appears. This is shown for the carbon-dioxide excretion, oxygen consumption, and heat production for all of the respiration experiments in tables 169 to 172.

Dextrose.

Ten experiments were made with 100 grams of dextrose with 9 subjects and four experiments with 75 grams of dextrose with two subjects. The greatest percentage increments are shown in table 169. In the experiments with 100 grams of dextrose the carbon-dioxide maximum increments show very large values. Thus, in no experiment was the maximum increment in the carbon-dioxide production

less than 12 per cent, while in one case it rose as high as 35 per cent, the average being 25 per cent. The average time at which the maximum values occurred was $1\frac{1}{2}$ to $1\frac{3}{4}$ hours after food. The oxygen consumption shows maxima with wide degrees of divergence, these ranging from 3 to 22 per cent, with an average for the 10 experiments of 12 per cent. The average time when this maximum appeared was between 1 and $1\frac{1}{4}$ hours after food. The heat production varied from 6 to 24 per cent above the basal value, the average being 14 per cent. Like the carbon-dioxide production, this maximum increment occurred on the average between $1\frac{1}{2}$ and $1\frac{3}{4}$ hours after food. We thus have a fairly consistent picture with 100 grams of dextrose of an average maximum increase of 25 per cent in the carbon-dioxide production, 12 per cent in the oxygen consumption, and 14 per cent in the heat production, with an average time after food for the appearance of the maximum of $1\frac{1}{2}$ to $1\frac{3}{4}$ hours.

TABLE 169.—*Maximum effect of ingestion of dextrose on carbon dioxide, oxygen, and heat in respiration experiments.*

Subject and date.	Period of observation.[1]	Carbon dioxide		Oxygen.		Heat (computed).	
		Greatest increment above basal value.	Hours after food.	Greatest increment above basal value.	Hours after food.	Greatest increment above basal value.	Hours after food.
100 grams dextrose.	*hrs. min.*	*p. ct.*		*p. ct.*		*p. ct.*	
K. H. A..May 14, 1912[2].	4 7	26	1 to $1\frac{1}{4}$	8	1 to $1\frac{1}{4}$	12	1 to $1\frac{1}{4}$
J. C. C...Dec. 31, 1912[3].	3 21	12	$1\frac{3}{4}$ to 2	8	$\frac{1}{4}$ to $\frac{1}{2}$	8	[4]$\frac{1}{4}$ to $\frac{1}{2}$
J. J. C...Mar. 7, 1911[3].	3 57	32	1 to $1\frac{1}{4}$	17	$\frac{1}{4}$ to $\frac{1}{2}$	20	1 to $1\frac{1}{4}$
L. E. E..May 29, 1911[3].	3 53	30	3 to $3\frac{1}{4}$	8	2 to $2\frac{1}{4}$	12	2 to $2\frac{1}{4}$
C. H. H..May 1, 1911[3].	6 6	22	1 to $1\frac{1}{4}$	20	$\frac{1}{2}$ to $\frac{3}{4}$	19	$\frac{1}{2}$ to $\frac{3}{4}$
H. L. H..May 24, 1911[3].	3 41	26	1 to $1\frac{1}{4}$	13	1 to $1\frac{1}{4}$	15	1 to $1\frac{1}{4}$
P. F. J...May 15, 1912[2]	3 55	20	$2\frac{1}{2}$ to $2\frac{3}{4}$	3	$\frac{3}{4}$ to 1	6	$2\frac{1}{2}$ to $2\frac{3}{4}$
B. M. K..Dec. 30, 1912..	5 0	24	$2\frac{1}{4}$ to $2\frac{1}{2}$	12	$2\frac{1}{4}$ to $2\frac{1}{2}$	14	$2\frac{1}{4}$ to $2\frac{1}{2}$
A. J. O...Dec. 11, 1914[5].	1 27	35	$1\frac{1}{4}$ to $1\frac{1}{2}$	22	$1\frac{1}{4}$ to $1\frac{1}{2}$	24	$1\frac{1}{4}$ to $1\frac{1}{2}$
Dr. P. R..May 3, 1912[2].	4 29	21	$\frac{3}{4}$ to 1	9	[6]$1\frac{1}{2}$ to $1\frac{3}{4}$	11	2 to $2\frac{1}{4}$
Average.....	4 0	25	$1\frac{1}{2}$ to $1\frac{3}{4}$	12	1 to $1\frac{1}{4}$	14	$1\frac{1}{2}$ to $1\frac{3}{4}$
75 grams dextrose.							
J. J. C...Dec. 22, 1910[3].	1 43	22	1 to $1\frac{1}{4}$	15	1 to $1\frac{1}{4}$	17	1 to $1\frac{1}{4}$
J. J. C...Dec. 28, 1910[2].	2 50	22	$1\frac{3}{4}$ to 2	8	$1\frac{3}{4}$ to 2	10	$1\frac{3}{4}$ to 2
V. G.....Dec. 23, 1910[3].	3 59	14	$2\frac{3}{4}$ to 3	15	1 to $1\frac{1}{4}$	15	1 to $1\frac{1}{4}$
V. G.....Dec. 29, 1910[2].	2 49	19	$1\frac{1}{4}$ to $1\frac{1}{2}$	8	$\frac{3}{4}$ to 1	9	$1\frac{1}{4}$ to $1\frac{1}{2}$
Average.....	2 50	19	$1\frac{3}{4}$ to 2	12	$1\frac{1}{4}$ to $1\frac{1}{2}$	13	$1\frac{1}{4}$ to $1\frac{1}{2}$

[1]Period from the time when subject finished eating to the end of the last observation, except in cases when the increment of heat ended earlier. See tables 126 to 139 for complete observations.

[2]Sugar taken with juice of one lemon on this day.

[3]Sugar taken with juice of one-half lemon on this day.

[4]Same value occurs $1\frac{1}{4}$ to $1\frac{1}{2}$ and $1\frac{3}{4}$ to 2 hours after food.

[5]In cereal coffee (about 300 c.c. solution).

[6]Same value occurs 2 to $2\frac{1}{4}$ hours after food.

In the 75-gram experiments the average of the maximum increment values for the carbon-dioxide production was 19 per cent and for the oxygen consumption was 12 per cent. The average of the maximum values for the heat production was 13 per cent, this being but slightly less than that found with 100 grams. Basing our conclusions upon these four experiments, therefore, the reduction in the amount of carbohydrate ingested from 100 to 75 grams produces but a relatively slight decrease in the maximum effect. The time at which this occurred was not greatly different from that in the 10 experiments with 100 grams of dextrose, being from $1\frac{1}{4}$ to $1\frac{1}{2}$ hours.

Thus, with dextrose, the results obtained with the respiration apparatus completely confirm the observations with the respiration calorimeter that the maximum effect with carbohydrates is obtained inside of the first 1 or 2 hours. The average length of the observations, *i. e.*, from the taking of the food to the end of the last experimental period, was 4 hours with 100 grams and 2^h50^m with the 75-gram amounts. It is clear that in both series of experiments the observation was sufficiently long to include the possible maximum effect.

Levulose.

With 100 grams of levulose 7 experiments were made with as many different subjects. (See table 170.) The carbon-dioxide production showed even greater maximum increments than in the case of the dextrose, namely, from 25 per cent to 38 per cent, with an average of 32 per cent. The maximum increment in the oxygen consumption ranged from 8 per cent to 14 per cent, with an average of 11 per cent. The "peak" effect in the heat production ranged from 11 per cent above basal to 18 per cent, with an average of 15 per cent. The experiments continued for an average length of 4^h10^m, the greatest exception being that with A. J. O., which was but 1^h29^m. On the average the maximum effect was obtained between $1\frac{1}{4}$ and $1\frac{1}{2}$ hours after the taking of food. Two experiments with but 75 grams, both with J. J. C., showed maximum values strikingly uniform with those obtained on the average with the 100-gram amount. Since there was but one subject, however, the comparison has no great value, particularly as no 100-gram experiment was made with this subject. Although the second experiment with J. J. C. was only 1^h15^m in length, it is probable that the maximum effect occurred in this time.

Sucrose.

Eight experiments with 100 grams sucrose and seven experiments with approximately 75 grams sucrose give a fairly good picture of the maximum effect due to the ingestion of sucrose. The data are shown in table 171. In the last three experiments with 100 grams the length of the observation was not so great as in the experiments previously considered, and in one or two instances the experiment was probably

terminated before the effect had ceased. As the time at which the maximum effect occurred agrees fairly well with that in the other experiments, these short experiments are included in table 171. With 100 grams of sucrose the carbon-dioxide increments were exceptionally large, ranging from 38 to 58 per cent, with an average of 47 per cent. With the oxygen consumption, the maximum increment ranged from 15 per cent to 27 per cent with an average of 20 per cent. The maximum increase in heat production ranged from 19 to 31 per cent with an average of 24 per cent. The highest increment occurred on the average from 45 to 60 minutes after the ingestion of the sugar.

TABLE 170.—*Maximum effect of ingestion of levulose on carbon dioxide, oxygen, and heat in respiration experiments.*

Subject and date.	Period of observation.[1]	Carbon dioxide.		Oxygen.		Heat (computed).	
		Greatest increment above basal value.	Hours after food.	Greatest increment above basal value.	Hours after food.	Greatest increment above basal value.	Hours after food.
100 grams levulose.	*hrs. min.*	*p. ct.*		*p. ct.*		*p. ct.*	
K. H. A..May 18, 1912[2]	3 38	32	1 to 1¼	14	¼ to ½	18	¼ to ½
J. P. C...Apr. 3, 1911[3]	5 24	33	2 to 2¼	14	2 to 2¼	18	2 to 2¼
L. E. E..May 22, 1911[3]	3 51	38	1¼ to 1½	8	1¼ to 1½	14	1¼ to 1½
C. H. H..May 16, 1911[3]	5 35	25	3½ to 3¾	13	2 to 2¼	15	2 to 2¼
H. L. H..June 1, 1911[3]	5 13	31	½ to ¾	8	½ to ¾	12	½ to ¾
P. F. J...May 22, 1912[2]	3 58	28	¾ to 1	9	3 to 3¼	11	[4]1¼ to1½
A. J. O...Dec. 8, 1914[5]	1 29	38	½ to ¾	14	½ to ¾	17	½ to ¾
Average.....	4 10	32	1¼ to 1½	11	1¼ to 1½	15	1 to 1¼
75 grams levulose.							
J. J. C...Dec. 31, 1910..	6 47	34	1¼ to 1½	16	1¼ to 1½	18	1¼ to 1½
J. J. C...Jan. 4, 1911[2].	1 15	30	¾ to 1	12	1 to 1¼	15	1 to 1¼
Average.....	4 1	32	1 to 1¼	14	1¼ to 1½	17	1¼ to 1½

[1]Period from the time when subject finished eating to the end of the last observation, except when the increment of heat ended earlier. See tables 140 to 148 for complete observations.
[2]Sugar taken with juice of one lemon on this day.
[3]Sugar taken with juice of one-half lemon on this day.
[4]Same value occurs 2¼ to 2½ hours after food.
[5]In cereal coffee (about 300 c.c. solution).

The experiments in which 75 grams of sugar were taken do not lend themselves so easily for comparison as the 100-gram experiments, since they were made with only two subjects. The maximum increase in carbon-dioxide production ranged from 21 per cent to 35 per cent with an average of 30 per cent, while that for oxygen consumption ranged from 5 to 13 per cent with an average of 11 per cent. The maximum increase in heat production ranged from 10 per cent to 18 per cent with an average of 15 per cent. Comparing these values with the averages

found after the ingestion of 100 grams, we find a marked decrease, amounting to one-third to one-half of the increment noted in the 100-gram experiments. With all three factors the time at which the maximum effect occurred is similar to that noted with the larger amount, namely, from 45 to 60 minutes after the ingestion of the carbohydrate.

TABLE 171.—*Maximum effect of ingestion of sucrose on carbon dioxide, oxygen, and heat in respiration experiments.*

Subject and date.	Period of observation.[1]	Carbon dioxide.		Oxygen.		Heat (computed).	
		Greatest increment above basal value.	Hours after food.	Greatest increment above basal value.	Hours after food.	Greatest increment above basal value.	Hours after food.
100 grams sucrose.	*hrs. min.*	*p. ct.*		*p. ct.*		*p. ct.*	
H. H. A..Jan. 2, 1912[2]	3 44	58	½ to ¾	15	2 to 2¼	22	[3]1 to 1¼
L. E. E..May 15, 1911[4]	2 34	48	¾ to 1	15	¾ to 1	22	¾ to 1
A. F. G..May 20, 1911[4]	3 52	43	1 to 1¼	27	1 to 1¼	31	1 to 1¼
C. H. H..May 10, 1911[4]	3 3	39	½ to ¾	22	½ to ¾	26	½ to ¾
H. L. H..May 17, 1911[4]	3 7	38	½ to ¾	16	½ to ¾	21	½ to ¾
Prof. C...Nov. 20, 1909[5]	1 4	51	0 to ¼	21	0 to ¼	25	0 to ¼
Prof. C...Nov. 22, 1909[5]	1 42	42	½ to ¾	17	¾ to 1	19	¾ to 1
A. J. O...Dec. 29, 1914[6]	1 30	55	½	24	¾ to 1	27	¾ to 1
Average.....	2 35	47	½ to ¾	20	¾ to 1	24	¾ to 1
75 grams sucrose.							
J. J. C...Nov. 22, 1910[4]	1 11	34	½ to ¾	13	½ to ¾	17	½ to ¾
J. J. C...Dec. 6, 1910[2]	5 39	35	¾ to 1	13	¾ to 1	18	¾ to 1
J. J. C...Dec. 8, 1910[2]	2 3	31	¾ to 1	10	¾ to 1	15	¾ to 1
J. J. C...Dec. 20, 1910[2]	2 52	32	½ to ¾	10	½ to ¾	14	½ to ¾
V. G.....Nov. 18, 1910[2]	1 34	21	¾ to 1	11	¾ to 1	13	¾ to 1
V. G.....Nov. 30, 1910[2]	3 54	29	1¾ to 2	12	1¾ to 2	15	1¾ to 2
V. G.....Nov. 21, 1910[4]	2 36	32	¾ to 1	5	[7]¾ to 1	10	¾ to 1
Average.....	2 50	30	¾ to 1	11	¾ to 1	15	¾ to 1

[1]Period from the time when subject finished eating to the end of the last observation, except in cases when the increment of heat ended earlier. See tables 149 to 163 for complete observations.
[2]Sugar taken with juice of one lemon on this day.
[3]Same value occurs 2 to 2¼ hours after food.
[4]73 grams sugar taken with juice of one-half lemon on this day.
[5]In 200 grams coffee.
[6]In cereal coffee (about 300 c.c. solution).
[7]Same value occurs 2¼ to 2½ hours after food.

LACTOSE.

Five observations with different subjects were made after the ingestion of lactose, the amount being 100 grams in all instances. The time of observation averaged 3h23m. (See table 172.) The carbon-dioxide increment ranged from 22 to 42 per cent with an average of 27 per cent, while the oxygen maxima ranged from 4 to 18 per cent with an average of 11 per cent. The greatest increase in heat production ranged from

8 to 23 per cent with an average of 14 per cent. The maximum effect for both carbon-dioxide production and heat production occurred on the average between $1\frac{1}{4}$ and $1\frac{1}{2}$ hours after the food was taken. The maximum for oxygen consumption was reached on the average 30 to 45 minutes after food.

TABLE 172.—*Maximum effect of ingestion of 100 grams of lactose on carbon dioxide, oxygen, and heat in respiration experiments.*

Subject and date.	Period of observation.[1]	Carbon dioxide.		Oxygen.		Heat (computed).	
		Greatest increment above basal value.	Hours after food.	Greatest increment above basal value.	Hours after food.	Greatest increment above basal value.	Hours after food.
	hrs. min.	*p. ct.*		*p. ct.*		*p. ct.*	
K. H. A..May 23, 1912[2]...	3 12	22	$1\frac{1}{4}$ to $1\frac{1}{2}$	4	[3]$\frac{1}{4}$ to $\frac{1}{2}$	8	$1\frac{1}{4}$ to $1\frac{1}{2}$
L. E. E..June 5, 1911[4]...	4 5	25	$\frac{3}{4}$ to 1	12	$\frac{3}{4}$ to 1	14	$\frac{3}{4}$ to 1
C. H. H..May 23, 1911[5]...	4 30	23	$2\frac{1}{2}$ to $2\frac{3}{4}$	15	$\frac{1}{4}$ to $\frac{1}{2}$	16	$2\frac{1}{2}$ to $2\frac{3}{4}$
H. L. H..June 7, 1911[5]...	3 38	24	$1\frac{1}{4}$ to $1\frac{1}{2}$	6	[6]$\frac{1}{2}$ to $\frac{3}{4}$	10	$1\frac{1}{4}$ to $1\frac{1}{2}$
A. J. O...Jan. 4, 1915[7]...	1 32	42	$\frac{3}{4}$ to 1	18	$\frac{3}{4}$ to 1	23	$\frac{3}{4}$ to 1
Average.....	3 23	27	$1\frac{1}{4}$ to $1\frac{1}{2}$	11	$\frac{1}{2}$ to $\frac{3}{4}$	14	$1\frac{1}{4}$ to $1\frac{1}{2}$

[1]Period from the time when subject finished eating to end of last observation, except in cases when the increment of heat ended earlier. See tables 164 to 168 for complete observations.
[2]Sugar taken with juice of one lemon on this day.
[3]Same value occurs $1\frac{1}{4}$ to $1\frac{1}{2}$ hours after food.
[4]Sugar taken with juice of two-thirds lemon on this day.
[5]Sugar taken with juice of one-half lemon on this day.
[6]Same value occurs $1\frac{1}{4}$ to $1\frac{1}{2}$ and $2\frac{3}{4}$ to 3 hours after food.
[7]In cereal coffee (about 300 c.c. solution).

COMPARISON OF MAXIMUM INCREMENTS OBTAINED WITH VARIOUS PURE CARBOHYDRATES.

A comparison of the percentages of greatest increase shown by the four sugars is given in table 173. The average period of observation was practically the same for all of the carbohydrates, although somewhat less in the experiments with sucrose and the 75-gram experiments with dextrose. In all cases the observation was sufficiently long to obtain the maximum effect.

The maximum increments in carbon-dioxide production for 100 grams of dextrose, levulose, and lactose were not far apart, being 25, 32, and 27 per cent, respectively, with an average maximum effect of 28 per cent; with sucrose the maximum increment was 47 per cent. A similar concordant effect is noted for the maximum increment in oxygen consumption for dextrose, levulose, and lactose, the highest values obtained being 12, 11, and 11 per cent, respectively, while with sucrose it was 20 per cent. The maximum increment in heat production was practically the same for dextrose, levulose, and lactose, *i. e.*, from 14 to 15 per cent. With sucrose it was materially greater, 24 per

cent. It is thus clear that the maximum effect was markedly different with sucrose from that for any one of the other sugars studied. So far as the time relations are concerned, it appears that not only was the increment very much greater with sucrose, but that the maximum effect also appeared earlier than it did with any of the other sugars. It is possible that the early occurrence of the maximum effect with sucrose may be due to the cleavage which probably occurs immediately after absorption.

TABLE 173.—*Average maximum effect of carbohydrate ingestion in respiration experiments.*

Kind of sugar.	Amt.	No. of experiments.	Period of observation.[1]	Carbon dioxide.		Oxygen.		Heat (computed).	
				Average maximum effect.	Hours after food.	Average maximum effect.	Hours after food.	Average maximum effect.	Hours after food.
	grams.		*hrs. min.*	*p. ct.*		*p. ct.*		*p. ct.*	
Dextrose.	100	10	4 0	25	1½ to 1¾	12	1 to 1¼	14	1½ to 1¾
	75	4	2 50	19	1¾ to 2	12	1¼ to 1½	13	1½ to 1¾
Levulose.	100	7	4 10	32	1¼ to 1½	11	1¼ to 1½	15	1 to 1¼
	75	2	4 1	32	1 to 1¼	14	1¼ to 1½	17	1½ to 1¾
Sucrose. .	100	8	2 35	47	½ to ¾	20	¾ to 1	24	¾ to 1
	75	7	2 50	30	¾ to 1	11	¾ to 1	15	¾ to 1
Lactose. .	100	5	3 23	27	1¼ to 1½	11	½ to ¾	14	1¼ to 1½

[1]Period from the time when subject finished eating to the end of the last observation, except in cases when the increment of heat ended earlier. See tables 126 to 168 for complete observations.

In all of the experiments either 75 or 100 grams of the sugar were used. With dextrose and levulose the amount of sugar made but little difference in the maximum effect, but there was considerable variation with sucrose. With the smaller amount of sucrose there was a decrease in the maximum effect, which amounted to one-third to one-half of the increment noted in the 100-gram experiments. A simple explanation of this phenomenon is not found. Although the 100-gram experiments with sucrose were on the average somewhat shorter than those with either dextrose or levulose, it is clear that this lowering of maximum increment can not be due to variations in the length of period, for the maximum, which alone is under consideration here, always occurs early in the experiment. It is furthermore clear that the sugar tolerance is by no means exceeded, as 100 grams is not a large amount.

One contaminating feature is the fact that in nearly every case the experiments with the two amounts were not made with the same individuals or with the same groups of individuals. All of the 75-gram experiments with the three sugars were made with either J. J. C. or V. G., and the only 100-gram experiment with these two subjects was that with J. J. C. on March 7, 1911, when dextrose was given. Still it is hardly probable that the fact that the same group of individuals was not used accounts wholly for this difference in effect. It is at least

possible that the disintegration of sucrose as a result of cleavage may have produced stimulating substances, such as intermediary acid products, in somewhat larger amounts than those occurring in the preparation of levulose for final combustion or storage in the body. The data do not permit of closer analysis in searching for a cause for this variation. It is evident, however, that following the ingestion of sucrose a considerably greater stimulus to the metabolism may be expected than that occurring with any of the other sugars, at least so far as the maximum effect is concerned.

TOTAL INCREMENT IN METABOLISM AFTER CARBOHYDRATE INGESTION (INDIRECT CALORIMETRY).

In the preceding section special emphasis has been laid upon the maximum increment in terms of percentage of the basal value—in other words, the absolute height to which the basal metabolism can be increased by the ingestion of different carbohydrates. As was pointed out in the consideration of the calorimeter experiments (see page 200), the total increment expressed as a percentage value can have but little significance, as the increase may extend over a considerable period of time and the basal value for this time will be directly proportional to the period; consequently the increment represents a continually decreasing percentage of the basal value. For these respiration experiments, therefore, it is likewise inexpedient to consider the percentage of total increment as referred to the basal value. On the other hand, it is perfectly feasible to compute the total increment in the metabolism. A series of tables has therefore been prepared showing the computed increments for carbon-dioxide production, oxygen consumption, and heat production in the period of observation following the ingestion of carbohydrate.

As already explained on page 151, the increment in heat production for practically all of the respiration experiments has been computed from measured areas representing heat values superimposed on a fasting base-line observed preceding the ingestion of food. The increases in heat production with carbohydrates were obtained in this manner. The increments for carbon-dioxide production and oxygen consumption have been found by a method somewhat different, but yielding practically the same result. As in the case of the plotted area for heat production, values were interpolated for the interval between the time when the subject finished eating and the beginning of the first measured period and for the intervals between the periods of measurement. For the interval preceding the first measured period it was assumed that the increment per minute was one-half that found in the period; for each interval between measured periods the average of the per-minute increments observed in the periods preceding and following the interval was used. Multiplication of the duration in minutes of the inter-

vals and measured periods by the respective increments per minute resulted in totals of either carbon dioxide produced or oxygen absorbed. The totals for periods and intervals, when added together, gave the amounts for the total period in which increment was observed. The computation of the increment began with the time when the subject had finished eating and continued to the end of the last period of the experiment, or through the period in which the increment apparently ceased.

The experiment of December 31, 1912, in which the subject J. C. C. took 100 grams dextrose, may be used to illustrate this method of computing the increment (see table 127, page 206). The basal value for carbon dioxide determined on the same day was 187 c.c. per minute. The amount per minute measured in the first period beginning at 11^h13^m a. m. was 196 c.c., or an increment of 9 c.c. per minute for the 14 minutes and 39 seconds of the period; the total increment observed in the period (14.65×9) is therefore 132 c.c. Between the time when the subject finished eating and the beginning of this period there was an interval of 8 minutes. Assuming for this interval an increment per minute of one-half that observed in the first period, the total increment for the preliminary interval (8×4.5) was 36 c.c. The increase in carbon dioxide for the second period beginning at 11^h45^m a. m. was 16 c.c. per minute, the total for the period (14.92×16) being 239 c.c. Between the first and second periods there was an interval of 17 minutes and 21 seconds; assuming a value equal to the average of the per minute increments in the first two periods, the total increase in carbon dioxide for this interval (17.35×12.5) was 217 c.c. The results for the remaining periods and intervals are obtained in the same manner and the total increase in carbon dioxide to the end of the sixth period following the ingestion of dextrose was, therefore, the sum of the computed and measured increments ($36+132+217+239+316+315+396+349+550+270+372+195$) or 3,387 c.c. The equivalent of this amount is 6.7 grams of carbon dioxide. For the same period of observation, *i. e.*, through the period ending at 2^h26^m p. m., the increment of oxygen computed and measured was 3 grams and the increase in heat obtained from the measured area of increment superimposed on the fasting base-line was 12 calories.

The total increments for each sugar studied are shown in tables 174 to 177. Although the maximum effect, as we have seen, was obtained usually inside of the first $1\frac{1}{2}$ hours after the ingestion of the sugar, there was a positive increment in carbon-dioxide production, oxygen consumption, and heat production, which was measurable for a fairly long period. Usually the increments in oxygen consumption and heat production persisted for about the same length of time, and thereafter basal values were obtained for both these factors. Frequently the increment in the carbon-dioxide production continued for some time

longer; the total excess carbon dioxide is therefore given in a footnote, together with the period of time in which it was obtained.

DEXTROSE.

The total increments in the metabolism as a result of the ingestion of dextrose are given in table 174. Considering first only the increments obtained with 100 grams of dextrose, we find that the total increment in carbon-dioxide production ranged from 6.7 to 20.4 grams with an average increment of 12.5 grams. The increase in oxygen consump-

TABLE 174.—*Total increment of carbon dioxide, oxygen, and heat following ingestion of dextrose in respiration experiments.*

Subject and date.	Period of observation.[1]		Increment of—		
			Carbon dioxide.	Oxygen.	Heat (computed).
100 grams dextrose.	*hrs.*	*min.*	*grams.*	*grams.*	*cals.*
K. H. A..May 14, 1912...	4	7	14.5	1.7	12
J. C. C...Dec. 31, 1912...	3	21	[2]6.7	3.0	12
J. J. C....Mar. 7, 1911...	3	57	20.4	8.2	35
L. E. E...May 29, 1911...	3	53	[3]17.1	3.4	18
C. H. H..May 1, 1911...	6	6	12.1	6.5	24
H. L. H..May 24, 1911...	3	41	[4]13.2	3.4	17
P. F. J...May 15, 1912...	3	55	9.4	0.6	6
B. M. K..Dec. 30, 1912...	5	0	11.7	5.7	21
A. J. O...Dec. 11, 1914...	1	27	7.2	3.7	14
Dr. P. R..May 3, 1912...	4	29	12.7	4.1	19
Average.....	4	0	12.5	4.0	18
75 grams dextrose.					
J. J. C....Dec. 22, 1910...	1	43	5.8	3.8	13
J. J. C....Dec. 28, 1910...	2	50	[5]8.5	1.6	8
V. G.....Dec. 23, 1910...	3	59	8.2	5.1	19
V. G.....Dec. 29, 1910...	2	49	8.6	3.6	15
Average.....	2	50	7.8	3.5	14

[1]Period from the time when subject finished eating to the end of the last observation, except in cases when the increment of heat ended earlier. See tables 126 to 139 for complete observations.
[2]7.1 grams for 4^h14^m. [3]20.8 grams for 5^h23^m. [4]18 grams for 4^h59^m. [5]11.7 grams for 5^h4^m.

tion ranged from 0.6 to 8.2 grams with an average of 4 grams, while the increment in heat production ranged from 6 to 35 calories with an average of 18 calories. The average length of the period of observation was 4 hours. In a few instances, namely, the experiments with J. C. C., L. E. E., and H. L. H., additional increments of 1 to 5 grams were obtained by further extension of the measurements. With the ingestion of 75 grams of dextrose the carbon-dioxide increment was reasonably constant, varying only from 5.8 to 8.6 grams with an average of 7.8 grams. The increment in the oxygen consumption ranged from 1.6 to 5.1 grams with an average of 3.5 grams, while the incre-

ment in the heat production ranged from 8 to 19 calories with an average of 14 calories. The total increments found with the different amounts of dextrose are noticeably unlike.

LEVULOSE.

The results obtained in the experiments with levulose are given similar treatment in table 175. The increments for carbon-dioxide production ranged from 9.9 to 23.3 grams with 100 grams of levulose, with an average value of 18.2 grams. Those for oxygen consumption varied from 3 to 8.3 grams, with an average of 5.1 grams, while the total increments for heat production ranged from 12 to 36 calories, averaging 24 calories. The two experiments with 75 grams of levulose are so widely divergent in their results that the data are of doubtful

TABLE 175.—*Total increment of carbon dioxide, oxygen, and heat following ingestion of levulose in respiration experiments.*

Subject and date.	Period of observation.[1]		Increment of—		
			Carbon dioxide.	Oxygen.	Heat (computed).
100 grams levulose.	*hrs.*	*min.*	*grams.*	*grams.*	*cals.*
K. H. A..May 18, 1912...	3	38	15.2	4.0	20
J. P. C...Apr. 3, 1911...	5	24	23.3	8.3	36
L. E. E...May 22, 1911...	3	51	23.2	3.1	21
C. H. H..May 16, 1911...	5	35	17.5	8.3	34
H. L. H..June 1, 1911...	5	13	21.8	4.5	24
P. F. J...May 22, 1912...	3	58	16.7	4.2	20
A. J. O...Dec. 8, 1914...	1	29	9.9	3.0	12
Average.....	4	10	18.2	5.1	24
75 grams levulose.					
J. J. C....Dec. 31, 1910...	6	47	25.3	9.7	38
J. J. C....Jan. 4, 1911...	1	15	8.1	2.3	10
Average.....	4	1	16.7	6.0	24

[1]Period from the time when subject finished eating to the end of the last observation, except in cases when the increment of heat ended earlier. See tables 140 to 148 for complete observations.

value, but as both show a positive increment for all three factors, they are included in this comparison. The average values for the two experiments are not far from the averages for the larger amount of levulose.

SUCROSE.

The experiments with 100 grams of sucrose, which are compared in table 176, show total increments in the carbon-dioxide production ranging from 9.8 to 26 grams and averaging 16.1 grams. In the experiment with L. E. E., May 15, 1911, approximately 6 grams additional excess carbon dioxide were obtained in the later periods of the experi-

ments. The total increment in oxygen consumption ranged from 3.9 to 7.8 grams, with an average of 5.9 grams, while the total increase in the heat production varied from 15 to 36 calories, averaging 25 calories. In the experiments with 75 grams of sucrose, with but two subjects, the total increment in the carbon-dioxide production varied widely from 4.7 to 20.4 grams, averaging 11.9 grams. The total increment in the oxygen consumption ranged from 1.9 to 5 grams with an average of 3 grams, while the increment in the heat production ranged from 9 to 27 calories, with an average of 15 calories. From these figures it is seen that the smaller amounts of sugar produced a smaller total increment in all three factors, thus corresponding more or less to the decrease in the maximum effects noted for the results obtained with the 100 grams and 75 grams.

TABLE 176.—*Total increment of carbon dioxide, oxygen, and heat following ingestion of sucrose in respiration experiments.*

Subject and date.	Period of observation.[1]		Increment of—		
			Carbon dioxide.	Oxygen.	Heat (computed).
100 grams sucrose.	*hrs.*	*min.*	*grams.*	*grams.*	*cals.*
H. H. A..Jan. 2, 1912...	3	44	26.0	7.7	36
L. E. E...May 15, 1911...	2	34	[2]18.4	4.7	24
A. F. G...May 20, 1911...	3	52	15.1	7.8	30
C. H. H..May 10, 1911...	3	3	15.7	7.0	28
H. L. H..May 17, 1911...	3	7	16.4	5.2	23
Prof. C...Nov. 20, 1909...	1	4	10.7	3.9	15
Prof. C...Nov. 22, 1909...	1	42	9.8	4.3	16
A. J. O...Dec. 29, 1914...	1	30	16.4	6.3	26
Average.....	2	35	16.1	5.9	25
75 grams sucrose.					
J. J. C....Nov. 22, 1910...	1	11	7.2	2.3	10
J. J. C....Dec. 6, 1910...	5	39	20.4	5.0	27
J. J. C....Dec. 8, 1910...	2	3	[3]11.1	1.9	11
J. J. C....Dec. 20, 1910...	2	52	[4]12.3	3.4	16
V. G.....Nov. 18, 1910...	1	34	[5]4.7	2.3	9
V. G.....Nov. 30, 1910...	3	54	16.9	4.0	21
V. G.[6]....Nov. 21, 1910...	2	36	10.7	1.9	12
Average.....	2	50	11.9	3.0	15

[1]Period from the time when subject finished eating to the end of the last observation, except in cases when the increment of heat ended earlier. See tables 149 to 163 for complete observations.
[2]23.9 grams for 5^h23^m [3]14.4 grams for 4^h9^m. [4]16.5 grams for 6^h5^m. [5]22 grams for 5^h40^m.
[6]73 grams sugar taken with juice of one-half lemon on this day.

LACTOSE.

The five experiments with lactose, grouped in table 177, show reasonable uniformity in the excess carbon dioxide produced, this ranging from 10.2 to 16 grams, with an average of 12.1 grams. In one

experiment with H. L. H., on June 7, 1911, which included a later 2-hour period, approximately 1 gram additional was excreted. The excess consumption of oxygen ranged from 1.8 to 6.4 grams, with an average of 4.3 grams, while the excess heat production varied from 10 to 22 calories, with an average of 18 calories. No experiments were made with less than 100 grams of lactose.

TABLE 177.—*Total increment of carbon dioxide, oxygen, and heat following ingestion of 100 grams lactose in respiration experiments.*

Subject and date.	Period of observation.[1]		Increment of—		
			Carbon dioxide.	Oxygen.	Heat (computed).
	hrs.	*min.*	*grams.*	*grams.*	*cals.*
K. H. A..May 23, 1912...	3	12	10.2	1.8	10
L. E. E...June 5, 1911...	4	5	16.0	5.2	22
C. H. H..May 23, 1911...	4	30	10.3	6.4	22
H. L. H..June 7, 1911...	3	38	[2]12.2	3.8	18
A. J. O...Jan. 4, 1915...	1	32	11.9	4.5	19
Average.....	3	23	12.1	4.3	18

[1]Period from the time when subject finished eating to the end of the last observation, except in cases when the increment of heat ended earlier. See tables 164 to 168 for complete observations.
[2]13.2 grams for 5^h31^m.

COMPARISON OF TOTAL INCREMENTS IN METABOLISM OBTAINED WITH VARIOUS PURE CARBOHYDRATES.

A comparison of the several carbohydrates in their effect upon the metabolism can best be made by a tabular presentation of the averages for the total increments obtained with the different carbohydrates in this series of experiments. Such a grouping has been made in table 178. Comparing particularly the increments for the 100-gram amounts, we see that the differences in the average total increments in the carbon-dioxide production are not so very large. The effect is most pronounced with levulose and least with lactose, that for sucrose lying between the levulose and dextrose increments. According to the standards used in the earlier studies of carbohydrates, in which special emphasis was laid upon the carbon-dioxide excretion, it would be considered that the effect with levulose was much more pronounced than that with sucrose and that the sugars affected the metabolism in these experiments in the decreasing order of levulose, sucrose, dextrose, and lactose. At first sight it is difficult to explain why the carbon dioxide produced should vary for the several sugars, and it is clear that the most careful analysis of the effect of sugar ingestion on the metabolism should not be based upon carbon-dioxide production. An examination of the increments in oxygen consumption shows that in this case the maximum increment was obtained with sucrose, the order of effect

being sucrose, levulose, lactose, and dextrose, the lactose being but slightly greater than the dextrose. With the heat production the lowest total increment was found with both dextrose and lactose; the increases with sucrose and levulose were considerably larger, that for the sucrose being one calorie greater than the levulose increment.

In the experiments with the 75-gram amounts, the general picture for the carbon-dioxide production is essentially the same as for the larger amount, the order being levulose, sucrose, and dextrose. For oxygen consumption and heat production the greatest increments were also obtained with levulose, but there were only two experiments with 75 grams of levulose, so that the averages are not perfectly comparable.

TABLE 178.—*Comparison of average increments of carbon dioxide, oxygen, and heat after 100 grams and 75 grams of carbohydrate in respiration experiments.*

Kind of sugar.	No. of experiments.	Carbon dioxide.	Oxygen.	Heat (computed).
100 grams:		*grams.*	*grams.*	*cals.*
Dextrose	10	12.5	4.0	18
Levulose	7	18.2	5.1	24
Sucrose	8	16.1	5.9	25
Lactose	5	12.1	4.3	18
Average of all sugars	..	14.7	4.8	21
75 grams:				
Dextrose	4	7.8	3.5	14
Levulose	2	16.7	6.0	24
Sucrose	7	11.9	3.0	15
Average of all sugars	..	12.1	4.2	18

From the general picture obtained from all of the experiments, one is justified in saying that if the carbon-dioxide production is used as a basis of comparison, the increment of the ingestion of sugars upon the metabolism decreased in the order of levulose, sucrose, dextrose, and lactose. If the effect is measured by oxygen consumption and heat production, this statement should be revised, for in general the levulose and the sucrose had essentially the same effect, but dextrose had a much less influence than the other sugars. An average of the increments for the individual sugars shows for the 100 grams a general increase for carbon-dioxide production of 14.7 grams, for oxygen consumption of 4.8 grams, and for heat production of 21 calories; the averages for the 75-gram amounts are somewhat smaller.

The statement made that the increment in the metabolism with sugars decreases in the order of levulose, sucrose, dextrose, and lactose, though based on the erroneous assumption that the carbon-dioxide incre-

ment with sugars would be proportional to the increment in the total metabolism, has been confirmed in other laboratories, although Lusk properly states that the differences are not very great. The data determined by Lusk[1] by indirect calorimetry after the ingestion of 50 grams of carbohydrates show that the increase over the basal metabolism during the second, third, and fourth hours was 30 per cent with glucose, 37 per cent with fructose, 34 per cent with sucrose, and but 3 per cent with lactose. By direct calorimetry he found a 15 per cent increase with glucose, 24 per cent with fructose, 28 per cent with sucrose, and 4 per cent with lactose. This latter series of values compares more nearly with those observed in our respiration experiments. Perhaps one of the most striking points in a consideration of the data in table 178 for these four sugars is the fact that the carbon-dioxide production, even with pure carbohydrates, is not a suitable measure of the energy transformations.

The clear superiority of levulose and sucrose over dextrose in influencing metabolism is difficult to explain. One may assume that levulose has a special action upon cellular metabolism and that it is the levulose moiety of the sucrose molecule that produces the effect with sucrose, and yet one would expect the effect to be quantitatively considerably less with sucrose than with levulose if this be true. Unfortunately the experiments with the smaller amount of levulose, namely, 75 grams, are unsatisfactory and few in number, one of the two being obviously erratic with a larger heat production than in any of the levulose experiments. We are hardly justified, therefore, in drawing definite conclusions regarding the amount of levulose which will produce a maximum stimulating effect. It is conceivable, however, that the effect of the sucrose due to the levulose portion may represent the maximum stimulating effect of levulose.

On the other hand, we have also to consider the energy due to the hydrolysis of the sucrose molecule, which is assumed to be not far from 3.1 per cent. If in the experiments with sucrose we consider that 100 grams of sucrose have an energy content of 400 calories, we should expect somewhat over 12 calories to be produced as the result of hydrolysis. Deducting the 12 calories from the average total increment of 25 calories obtained in our sucrose experiments, we find that there are 13 calories left which can be attributed to the influence of the separate components, levulose and dextrose, upon the metabolism. Assuming that the 100 grams of sucrose result in the formation of 50 grams each of levulose and dextrose, and using the average increments for 100 grams of these substances of 24 and 18 calories, respectively, which were found in our experiments, we would expect to obtain an effect of 12 plus 9 calories, or 21 calories, if the effect is a summation effect. It is clear, therefore, that the explanation of the 25 calories due to the ingestion of

[1]Lusk, Journ. Biol. Chem., 1915, **20**, p. 590.

100 grams of sucrose does not rest upon the summation effect of the resultant dextrose and levulose and the heat production due to hydrolysis, but that there must obviously be a compensation. Furthermore, the cells may refuse to react to the indirect stimulus of the result of hydrolysis and the direct stimulus of the two sugars on the basis of a summation effect. With practically all of the sugars except levulose, a somewhat decreased effect was found with the smaller amount of sugar. With levulose, therefore, we have a specific property entirely different from that found with the other sugars and in all probability we have here an intermediary metabolism which may perhaps best be considered in connection with the study of the respiratory quotient.

THE RESPIRATORY QUOTIENT AFTER INGESTION OF CARBOHYDRATES.

Although the basal values for the respiratory quotients for the calorimeter experiments were not secured in all cases on the same day, quotients considerably above 0.90 were frequently obtained in the food experiments, which led to the reasonable assumption that there was a pronounced rise in this relationship, since the respiratory quotient for normal individuals in the post-absorptive condition is not far from 0.81 to 0.83. In the respiration experiments a careful study of the respiratory quotients for short periods could be made; these have been recorded in tables 179 to 182 and show the time relations as well as the height of the quotients. In these tables we are considering only the quotients obtained in experiments with 100 grams of carbohydrate.

Dextrose.

The respiratory quotients for 10 experiments with dextrose are given in table 179. As will be seen from the protocols of these experiments, the post-absorptive value for the respiratory quotient was in practically every case an average of two or three reasonably agreeing periods. These values ranged from the low quotient of 0.70 to 0.87 with an average of 0.80. If we study the course of the respiratory quotient in the experiments, we find that shortly after the carbohydrate was given there was in practically every case a pronounced tendency for the quotient to reach a maximum about the second or third hour, and to fall off thereafter. It should be remembered, in studying these quotients, that each value depends upon the determinations of a single period and hence the general picture alone should be considered. The rise followed by a fall is so clear, however, as to leave no doubt as to the general course of the quotient after the ingestion of dextrose. An examination of the average values shows that within 20 minutes of the beginning of the experiment there was a slight fall from the average basal quotient of 0.80, which was followed by a steady increase until the maximum of 0.92 was reached in 2 to $2\frac{1}{2}$ hours; subsequently there was a tendency for the quotient to decrease.

On examination of the individual experiments, we find that in the two observations with the lowest basal value the maximum height of the respiratory quotient after food was also the lowest. Thus, in the experiment with J. C. C. on December 31, 1912, in which the initial quotient was 0.74, the highest quotient obtained was but 0.81, while in the experiment with B. M. K. on December 30, 1912, with a basal quotient of 0.70, the maximum quotient was 0.79. In these two instances a low glycogen store in the body at the beginning of the experiment can be inferred. This inference is further substantiated by the fact that a few days prior to this test these two subjects were living on a carbohydrate-free diet taken during a series of acidosis experiments.

TABLE 179.—*Influence of ingestion of 100 grams dextrose on the respiratory quotient in respiration experiments.*

Subject and date.	Basal value.	Time after ingestion of dextrose.											Maximum rise.
		0 to 20 min.	20 to 40 min.	40 to 60 min.	1 to 1½ hrs.	1½ to 2 hrs.	2 to 2½ hrs.	2½ to 3 hrs.	3 to 4 hrs.	4 to 5 hrs.	5 to 6 hrs.	6 to 7 hrs.	
K. H. A..May 14, 1912	0.84	...	0.85	...	0.98	1.01	1.00	...	1.00	0.89	...	...	0.17
J. C. C...Dec. 31, 1912	.74	0.72	...	0.77	.78	.78	...	0.81	.81	.72	...	...	.07
J. J. C...Mar. 7, 1911	.79	...	.79	...	.89	.90	.92	.94	...	...	...	...	.15
L. E. E..May 29, 1911	.78	...	.82	...	.88	.92	.91	...	[1].94	.80	...	...	.16
C. H. H..May 1, 1911	.87	...	...	.85	.91	.93	.94	.82	.90	...	0.93	0.87	.07
H. L. H..May 24, 1911	.82	...	.78	...	.91	.94	.98	.94	.94	[2].84	...	...	.16
P. F. J...May 15, 1912	.84	...	...	.89	.91	...	.97	.99	[3].93	...	...	...	.15
B. M. K..Dec. 30, 1912	.70	.67	...	.73	...	...	.77	...	.79	[4].74	...	...	.09
A. J. O...Dec. 11, 1914	.87	[5].88	[6].91	.94	.96	...	...	...	...	...	...	...	.09
Dr. P. R..May 3, 1912	.78	.76	.83	.91	...	.86	.87	.87	.89	.90	...	...	.13
Average.....	0.80	0.76	0.83	0.85	0.90	0.91	0.92	0.90	0.90	0.82	0.93	0.87	0.12

[1]Average of two quotients, 0.96 and 0.91.
[2]Average of two quotients, 0.88 and 0.80.
[3]Average of two quotients, 0.99 and 0.87.
[4]Average of two quotients, 0.76 and 0.72.
[5]Average of four quotients, 0.91, 0.85, 0.87, and 0.87 (3 to 5 minute periods).
[6]Average of two quotients, 0.90 and 0.91 (5 minute periods).

The comparison of the maximum increases in the respiratory quotients for the individual experiments, which is given in the last column, shows the lowest maximum rise to be 7 points above the basal, the highest 17 points, and the average maximum rise 12 points. While the lowest maximum rise was obtained in the experiment with the glycogen-poor subject J. C. C., it should be further noted that in an experiment with C. H. H. on May 1, 1911, in which the initial quotient was 0.87, there was the same rise of but 7 points; the relationship between the initial value and the maximum rise in the quotient is therefore by no means definitely established. In general, however, if the initial value is low, the maximum rise in the quotient is also low.

With dextrose the quotient for only one period was over unity. As it has been shown that the non-protein respiratory quotients are generally two or three points higher than the measured quotients, all values of 0.98 or over would, strictly speaking, represent a non-protein respiratory quotient of unity. Even on this basis but relatively few periods, *i. e.*, 6 periods, show a non-protein respiratory quotient above 1. Respiratory quotients above 1 are commonly considered to indicate the formation of fat from carbohydrate. Furthermore, it is often inferred that the formation of fat from carbohydrate can occur only when the respiratory quotient is above 1, but this we do not believe to be true.

Levulose.

The respiratory quotients in 7 experiments with levulose are given in table 180. The post-absorptive basal quotients range from 0.77 to 0.91, with an average of 0.85, somewhat higher than for the dextrose basal quotients, which averaged only 0.80. The general course of any one of the experiments is characteristic of the whole series in that there is an almost immediate rise after the ingestion of the carbohydrate and a tendency after several hours to return to approximately the basal value. The height of the respiratory quotient is much greater on the whole than was obtained with dextrose, as in all but one experiment it reached 1 or over. The lowest basal quotient, 0.77, was accompanied by one of the lowest maxima after food, while the highest basal quotient of 0.91 was followed by the highest observed maximum, 1.11.

Table 180.—*Influence of ingestion of 100 grams levulose on the respiratory quotient in respiration experiments.*

Subject and date.	Basal value.	Time after ingestion of levulose.										Maximum rise.
		0 to 20 min.	20 to 40 min.	40 to 60 min.	1 to 1½ hrs.	1½ to 2 hrs.	2 to 2½ hrs.	2½ to 3 hrs.	3 to 4 hrs.	4 to 5 hrs.	5 to 6 hrs.	
K. H. A..May 18, 1912	0.82	...	0.94	1.00	...	0.97	0.92	0.91	0.86	...	...	0.18
J. P. C...Apr. 3, 1911	.85	...	1.01	...	1.03	.98	1.00	...	.89	0.90	0.85	.18
L. E. E...May 22, 1911	.77	...	.94	...	.98	...	.95	1.00	.89	.79[1]	...	.23
C. H. H..May 16, 1911	.88	0.93	...	.97	.97	...	.94	.90	.99	.94	.86[2]	.11
H. L. H..June 1, 1911	.83	...	1.02	...	.98	...	1.00	.90	.96	.88	.82	.19
P. F. J...May 22, 1912	.91	...	1.07	1.11	1.03	...	1.00	.96	.93	...	...	.20
A. J. O...Dec. 8, 1914	.90	1.05[3]	1.08[4]	1.09	.98	...	...	...	...	...	...	.19
Average.....	0.85	0.99	1.01	1.04	1.00	0.98	0.97	0.93	0.92	0.88	0.84	0.18

[1]Average of two quotients, 0.82 and 0.76.
[2]Average of two quotients, 0.85 and 0.86.
[3]Average of four quotients, 0.96, 1.07, 1.09, and 1.07 (3 to 5 minute periods).
[4]Average of two quotients, 1.10 and 1.05 (5-minute periods).

As the time of determining the quotients was not the same in all of the experiments, necessitating several gaps in their arrangement in the

table, the averaging of the values is somewhat open to criticism; nevertheless they give a clear picture of the general course of the quotient after the food was taken. The basal value of 0.85 was followed by a rise to 0.99 within 20 minutes of the beginning of the experiments and the maximum rise of 1.04 was obtained in 40 to 60 minutes. Between the fifth and sixth hours the average quotient returned to essentially the basal value. The quotients with levulose are therefore characterized by a sharp rise, with an average maximum rise of 18 points. The maximum quotients ranged in the individual experiments from 11 points above the basal value in the experiment with C. H. H., May 16, 1911, to 23 points with L. E. E. on May 22, 1911. The number of respiratory quotients of 0.98 or over, showing a non-protein respiratory quotient above 1, is very large, there being 19 in all. The highest value observed was 1.11 and values as high as 1.09 and 1.07 are of frequent occurrence.

It is clear that there is a specific property of levulose that is markedly different from dextrose in its effect on the metabolism, both quantitatively and (as is now seen) qualitatively. To what extent this is determined by direct and rapid combustion, intermediary processes in transformation to glycogen or fat, or to the stimulating action of intermediary products may not at present be stated with surety.

Sucrose.

A study of the respiratory quotients after the ingestion of sucrose is given in table 181. The post-absorptive values for these experiments ranged from 0.72 to 0.88, with an average value of 0.83. The general course of the quotient after the ingestion of the carbohydrate was uniform for practically all of the experiments, *i. e.*, an immediate marked rise reaching the maximum usually inside of the first hour of the experiment, this being followed by a continuous and slow return to approximately the basal value. The number of quotients 0.98 or over is 16. A considerable number of quotients of 1 or over appear inside of the first 40 minutes, the average maximum of 1.03 occurring in the 20 to 40 minute period.

The maximum rise in the quotient was reached in the experiment with H. H. A. on January 2, 1912, when an increment of 33 points over the basal was obtained. This is of special significance, as the subject had an extraordinarily low initial quotient of 0.72, which was due to the fact that he had just completed a series of experiments with a carbohydrate-free diet and was in consequence supposedly in a glycogen-poor condition. The course of the quotient in this experiment, which showed an immediate great rise with a maximum inside of 40 minutes and a subsequent period of 3 hours with quotients of 0.84 or above, is somewhat difficult to explain. The fact that this man showed a less severe degree of acidosis than usual on the carbohydrate-free diet is of

TABLE 181.—*Influence of ingestion of 100 grams sucrose on the respiratory quotient in respiration experiments.*

Subject and date.	Basal value.	Time after ingestion of sucrose.										Maximum rise.
		0 to 20 min.	20 to 40 min.	40 to 60 min.	1 to 1½ hrs.	1½ to 2 hrs.	2 to 2½ hrs.	2½ to 3 hrs.	3 to 4 hrs.	4 to 5 hrs.	5 to 6 hrs.	
H. H. A...Jan. 2, 1912	0.72	0.87	1.05	...	0.98	...	0.93	0.84	0.76	...	...	0.33
Prof. C....Nov. 20, 1909	.86	1.07	1.06	0.98	...	...	...	...	...	...	...	.21
Prof. C....Nov. 22, 1909	.88	...	1.10	.98	.91	0.90	...	...	...	...	...	.22
L. E. E....May 15, 1911	.78	...	.93	1.00	...	.98	...	.93	.87	0.83	0.76	.22
A. F. G....May 20, 1911	.86	...	.95	...	.97	...	.93	...	[1].83	...	...	.11
C. H. H...May 10, 1911	.86	...	.98	.90	...	.96	.99	.90	.87	.84	...	.13
H. L. H...May 17, 1911	.82	...	...	.99	.94	...	...	.96	.83	.78	...	.17
A. J. O....Dec. 29, 1914	.88	[2]1.08	[3]1.13	1.00	1.03	...	...	...	...	...	...	.25
Average.....	0.83	1.01	1.03	0.98	0.97	0.95	0.95	0.91	0.83	0.82	0.76	0.21

[1]Average of two quotients, 0.83 and 0.82.
[2]Average of three quotients, 1.03, 1.08, and 1.12 (3 to 5 minute periods).
[3]Average of three quotients, 1.14, 1.14, and 1.11 (5 minute periods).

special interest in this connection as possibly indicating a greater storage of glycogen or a more tenacious hold of the previous store than is ordinarily the case.[1]

The smallest rise in the quotient was obtained in the experiment with A. F. G. on May 20, 1911, this being but 11 points above the basal. The averages for all of the experiments show, with an average basal quotient of 0.83, a maximum value after the ingestion of sucrose of 1.03. The average maximum rise was 21 points. It should be observed that the average is obtained in this and similar tables by averaging the maximum increases for the individual experiments.

LACTOSE.

The respiratory quotients in five experiments with 100 grams of lactose are given in table 182. The basal values were remarkably uniform, ranging from 0.81 to 0.84, with an average of 0.83. None of the men had served as subjects for the carbohydrate-free experiments. Without laying stress upon the individual experiments and considering only the general picture, we find that there was a slow, steady rise in the quotient which was followed by a fall; the rise in this series was longer continued than in any of those previously discussed. Values of 0.98 or over are rare in the experiments with lactose, there being but three in all. The maximum rise of 18 points was found in the experiment with K. H. A., May 23, 1912; the minimum rise of 7 points occurred with C. H. H., on May 23, 1911; the average maximum rise for the whole series was 14 points.

[1]Benedict and Joslin, Carnegie Inst. Wash. Pub. No. 176, 1912, p. 131.

TABLE. 182.—*Influence of ingestion of 100 grams laclose on the respiratory quotient in respiration experiments.*

Subject and date.	Basal value.	Time after ingestion of lactose.										Maximum rise.
		0 to 20 min.	20 to 40 min.	40 to 60 min.	1 to 1½ hrs.	1½ to 2 hrs.	2 to 2½ hrs.	2½ to 3 hrs.	3 to 4 hrs.	4 to 5 hrs.	5 to 6 hrs.	
K. H. A..May 23, 1912	0.81	...	0.79	...	0.95	...	0.96	0.95	0.99	...	...	0.18
L. E. E...June 5, 1911	.83	...	...	0.93	.94	0.92	...	.96	.92	...	...	.13
C. H. H..May 23, 1911	.83	...	.79	.84	.90	.88	...	.89	[1].85	0.81	0.73	.07
A. J. O...Jan. 4, 1915	.84	[2]0.90	[3]1.01	1.01	.95	...	...	...	...	...	...	.17
H. L. H..June 7, 1911	.82	...	.84	...	.96	...	.93	.90	.88	.81	.79	.14
Average.....	0.83	0.90	0.86	0.93	0.94	0.90	0.95	0.93	0.91	0.81	0.76	0.14

[1]Average of two quotients, 0.86 and 0.84.
[2]Average of four quotients, 0.88, 0.88, 0.90, and 0.94 (3 to 5-minute periods).
[3]Average of two quotients, 1.01 and 1.01 (5-minute periods).

COMPARISON OF RESPIRATORY QUOTIENTS OBTAINED WITH VARIOUS PURE CARBOHYDRATES.

A comparison of the respiratory quotients obtained after the ingestion of various sugars is made in table 183, in which the number of experiments, the average post-absorptive values, the average quotients with their time relations, and the total rise are given for each of the sugars studied, only the results obtained with 100 grams being included in this summary. Except in the case of dextrose, the preliminary post-absorptive values were practically the same. That for dextrose, 0.80, was the lowest; the highest average basal quotient, 0.85, was obtained with levulose. The quotients after the ingestion of a carbohydrate show a rise in the first 20 minutes, with dextrose the only exception; the average quotient for dextrose fell from 0.80 to 0.76 during this period. Reference to table 179, from which this figure is drawn, shows that in three of the four experiments included in the average there was a positive decrease in the first period and that in the fourth experiment there was a rise of but one point. The explanation of the exceptional values found with dextrose is not simple. While we are much averse to using the commonplace sentence frequently employed by observers to explain anomalies, *i. e.*, "similar values are found by investigators X, Y, and Z," we should state that this particular point has also been observed and discussed by Durig,[1] who says that it is due to an increase in the oxygen consumption and not to a modification of the respiration or an increase in the work of respiration following a preliminary over-ventilation.

After the first 20 minutes the course of the respiratory quotient was much the same for all of the sugars, namely, a distinct increase followed by a decrease. The levulose quotients indicate a much greater and more immediate effect than do the dextrose experiments, the maxi-

[1]Tögel, Brezina, and Durig, Biochem. Zeitschr., 1913, **50,** p. 308.

TABLE 183.—*Average respiratory quotients at intervals following the ingestion of 100 grams pure carbohydrate in respiration experiments.*

	Dextrose.	Levulose.	Sucrose.	Lactose.
No. of experiments	10	7	8	5
Basal value	0.80	0.85	0.83	0.83
Time after ingestion of carbohydrate:				
0 to 20 minutes	0.76	0.99	1.01	0.90
20 to 40 minutes	.83	1.01	1.03	.86
40 to 60 minutes	.85	1.04	.98	.93
1 to 1½ hours	.90	1.00	.97	.94
1½ to 2 hours	.91	.98	.95	.90
2 to 2½ hours	.92	.97	.95	.95
2½ to 3 hours	.90	.93	.91	.93
3 to 4 hours	.90	.92	.83	.91
4 to 5 hours	.82	.88	.82	.81
5 to 6 hours	.93	.84	.76	.76
6 to 7 hours	.87	....	....	....
Average maximum rise	0.12	0.18	0.21	0.14

mum figure in the case of levulose appearing in 40 to 60 minutes, while the dextrose quotients remain essentially at the same level from the first to the fourth hour after the beginning of the experiment, with an absolute maximum from 2 to 2½ hours. With sucrose the maximum effect appeared 20 to 40 minutes after the beginning of the experiment, while with lactose the maximum was found in the same period as with dextrose, *i. e.*, in the 2 to 2½ hour period.

It should be remembered that occasionally the quotients given in this table represent values for a single period. For instance, the quotient 0.87 for the sixth to seventh hours with dextrose was obtained in one period (see table 179), while the figure 0.76 given for the fifth to the sixth hours with sucrose is also an individual value. As a rule, however, the quotients given in this table are the average of three or four values and may be considered as reasonably representative of true averages.

The highest absolute values were recorded in the levulose experiments, although the sucrose maximum of 1.03 is but little less than the levulose maximum. It should furthermore be noted that the values for dextrose are lower throughout all of the periods; it is true that the basal value was also lower, but if a correction of 5 points is made in the maximum of 0.92, we should obtain a quotient of only 0.97, which would be measurably lower than the maximum with either levulose or sucrose. Similarly it is clear that the lactose values are measurably lower than those for sucrose or levulose. The average maximum rise with dextrose is 12 points, lactose 14 points, levulose 18 points, and sucrose 21 points. Thus we see that not only do levulose and sucrose exert an effect upon the metabolism which is shown in the quantitative relations of the total measurable metabolic factors (see table 178), but they likewise possess specific characteristics which affect the char-

acter of the metabolism, this fact being indicated by a great rise in the respiratory quotient. If we apply a rough correction of 3 points for the conversion of these quotients to non-protein quotients, we should find that none of the quotients would reach 1 with dextrose and lactose, but with levulose the non-protein quotients would be either 1 or above for the first $2\frac{1}{2}$ hours of the experiment, while those for sucrose would appear for the first $1\frac{1}{2}$ hours. The general course of the respiratory quotient shows, therefore, that the effect on the character of the metabolism parallels the effect upon the total metabolism; that is, it is in large part confined to the first hours after the taking of carbohydrate.

GENERAL DISCUSSION OF RESULTS OBTAINED WITH PURE CARBOHYDRATES.

The increase in the respiratory quotient subsequent to the ingestion of carbohydrate is in practically all instances due to a pronounced rise in the carbon-dioxide production rather than to a decrease in the oxygen consumption; the latter is also increased in the majority of instances. This increase in the carbon-dioxide production, which is the only factor measured in Johansson's experiments, certain experiments of Gigon, and a large number of Rubner's, does not indicate accurately the effect upon the metabolism itself as measured either directly in calorimeter experiments or by indirect calorimetry when both the carbon-dioxide and oxygen determinations are made. The increase in the carbon-dioxide production observed after carbohydrate ingestion may have three explanations:

As can be inferred from the average basal respiratory quotient, the katabolism during the post-absorptive period is a protein-fat-carbohydrate katabolism. When carbohydrate has been ingested, fat may be completely excluded from the katabolism, and we then have a protein-carbohydrate katabolism; under these conditions the proportion of carbon dioxide produced will be larger than that when fat is used in the production of a like amount of energy. Hence one explanation of the increase in carbon-dioxide production may be that it is due simply to a replacement of fat by carbohydrate in the metabolism.

Second, the increment in carbon-dioxide may be derived in appreciable amounts from a cleavage of carbon-dioxide from carbohydrate in the formation of fat. The formation of fat as a result of excessive carbohydrate feeding is no longer in question, for the experiments of Meissl[1] and of Bleibtreu[2] on swine and geese, to say nothing of the many experiments with man and other animals than swine and geese, have shown this conclusively. With the ingestion of 100 grams of pure carbohydrate, there is immediately made available 380 to 400 calories, while the basal requirement may not exceed 70 to 90 calories per hour. The sugar ingested would therefore logically suffice for the

[1]Meissl, Zeitschr. f. Biol., 1886, **22**, p. 63.
[2]Bleibtreu, Arch. f. d. ges. Physiol., 1901, **85**, p. 345.

basal requirement of a period of 5 to 6 hours, during which time we may properly say the conditions are those of excessive carbohydrate feeding. Just what is meant by excessive carbohydrate feeding is, of course, in large part dependent upon the period between the feedings and the total amount ingested, but logically there is no reason why the above argument is not sound. It is fair to assume, therefore, that part of the carbon-dioxide may be derived from the cleavage of carbohydrate to form fat.

Third, an increased carbon-dioxide excretion may result from an actual increase in metabolism, during which process additional carbonaceous material is burned, with a resultant increase in the production of carbon dioxide. This fact is of prime importance, since the measurement of oxygen consumption, and particularly of heat production, will likewise indicate such an increase in metabolism.

If only the carbon-dioxide excretion is measured, it is impossible even to estimate the varying amounts due to each one of these three factors. On the other hand, when the oxygen consumption or heat production is determined, we have definite information as to the probable amount of excess carbon dioxide due to an increase in metabolism. The fact has already been clearly established by direct calorimetry, and is substantiated by indirect calorimetry, that the ingestion of carbohydrate in these experiments actually results in an increased heat production, that is, an increased metabolism entirely aside from intermediary transformations. Indeed, the heat production, as indicated in the data for the calorimeter experiments, is of such a magnitude as completely to preclude the assumption that the extra heat produced is due solely to hydration or simple cleavage. We may therefore properly consider that the ingestion of carbohydrate, particularly of sucrose and levulose, results in a direct stimulus to the total metabolism in the body.

The marked rise in the respiratory quotient also leads to the firm conviction that the fat combustion must, in large part, have been replaced by carbohydrate metabolism, at least in those experiments in which the respiratory quotient closely approaches unity. With respiratory quotients of 0.97, which by correction would result in non-respiratory quotients of unity, we may likewise assume that the non-protein metabolism is due to carbohydrate, an assumption which seems legitimate in view of the fact that quotients of this character frequently appear in our series. On the other hand, quotients considerably above unity also frequently appear, especially in the levulose and sucrose experiments. These distinctly imply, if not absolutely prove, the formation of fat from carbohydrate. It still remains a question as to whether this latter process, namely, the formation of fat from carbohydrate, may not proceed even when there is a somewhat lower respiratory quotient than that of unity. With the marked differences in the action of the several sugars on the total metabolism, and par-

ticularly on the respiratory quotient, it is conceivable that with the ingestion of sucrose or levulose the fat metabolism may not be completely suppressed and that we may have a very considerable formation of fat from carbohydrate with a slight fat combustion still progressing. The actual proof of this is, however, beyond the possibilities of existing technique.

The intermediary processes must be still further considered and the fact recognized that when the body is surcharged with carbohydrate, as it is after the ingestion of 100 grams of sugar, there may result a considerable deposit of glycogen. This process would be without action upon the respiratory quotient and one might suppose it to be without action upon the total metabolism. It is nevertheless a fact that in the experiments with an initial respiratory quotient so low as to suggest a glycogen-poor reserve there was no evidence of a sufficient storage in the body of the ingested carbohydrate to produce a marked decrease in its effect upon the total metabolism.

One of the most striking illustrations of this fact was in the experiment with H. H. A. on January 2, 1912, in which 100 grams of sucrose were given (see table 176). The store of glycogen in the body of this subject was presumably very low, as evidenced by the basal respiratory quotient of 0.72. This was due to the fact that a few days previous he had been the subject of a series of experiments with a carbohydrate-free diet. If this subject had first replenished his glycogen store with carbohydrate before the ingested material was katabolized or before any portion of it was converted to fat, we should not expect an immediate increment of either the total metabolism or the respiratory quotient. As a matter of fact, the ingestion of 100 grams of sucrose in this particular case resulted in the maximum increment for the entire series with sucrose in both the heat and carbon-dioxide production and very nearly the maximum rise in the oxygen consumption. We have already observed (table 181) that inside of 40 minutes the quotient rose from 0.72 to 1.05 and remained at a rather high value for at least two subsequent observations, the quotients being 0.98 and 0.93. Still another illustration of this lack of evidence as to glycogen storage is supplied by the levulose experiment with L. E. E. on May 22, 1911 (see table 180). Although the post-absorptive quotient of 0.77 was the lowest obtained in this series, the ingestion of 100 grams levulose produced very nearly the largest excess carbon dioxide, namely, 23.2 grams, 3.1 grams excess oxygen, and 21 calories of excess heat (see table 175).

It is a source of regret that the series of experiments with carbohydrates did not include a larger number with both glycogen-poor and glycogen-rich subjects. As has been shown by previous tests in this laboratory,[1] it is perfectly feasible to obtain a glycogen-poor condition by one or two days of carbohydrate-free diet. Durig, with his

[1]Higgins, Peabody, and Fitz, Journ. Med. Research, 1916, **34**, p. 263.

keen foresight, recognized the significance of this question and carried out one experiment in which an attempt was made to have the subject in a glycogen-poor condition, but the initial respiratory quotient of this subject, 0.799,[1] did not indicate a much lower glycogen storage than that of his two previous experiments with quotients of 0.835 and 0.809, respectively.

To sum up, the experiments upon the ingestion of carbohydrate show clearly that carbon-dioxide measurements have little significance if unaccompanied by measurements of either the oxygen consumption or the heat production. The increment in the carbon-dioxide production invariably noted may be caused by three different factors, all of which may be working together, but an actual increase of the heat production can only be shown by oxygen measurements or by direct calorimetric measurements. In considering the three causes for the increment in carbon dioxide, *i. e.*, the replacement of fat by carbohydrate in the metabolism, the formation of fat from carbohydrate, or an actual increase in the total katabolism (all of which involve a destruction of carbohydrate) the disappearance of carbohydrate after ingestion due to possible glycogen storage in the body should not be lost sight of. Presumably this latter condition will be best favored by a depletion of the glycogen store in the body previous to the ingestion of the carbohydrate.

Since the protein katabolism in these experiments plays such a relatively small rôle, rarely over 15 per cent of the total heat production being derived from protein, we can practically neglect the intermediary transformations of protein in our calculations. Sufficient evidence has, however, been accumulated to show that the contention of Gigon, *i. e.*, that in the *nüchtern* or post-absorptive condition there is constancy in both the nitrogen content of the urine and the character of the katabolism as indicated by the respiratory quotient, can not hold true. The data in this publication make clear the fact that respiratory quotients of the same individual may vary greatly. The careful series of experiments published by Tögel, Brezina, and Durig,[2] also show that with the same subject the basal post-absorptive respiratory quotient varied inside of a period of less than 4 months from 0.799 to 0.903. While, therefore, we are fully cognizant of the extremely suggestive and stimulating discussion by Gigon of the constancy of the basal cellular metabolism, established, as he thought, by his determinations of the nitrogen, carbon-dioxide excretion, and basal metabolism, yet we firmly believe that subsequent data can not confirm his assertion (see footnote 2, page 264). In our series of experiments it is wholly impossible to conceive of a constant nitrogen metabolism with a constant fat metabolism on which the carbohydrate metabolism is simply superimposed.

[1] Tögel, Brezina, and Durig, Biochem. Zeitschr., 1913, **50**, p. 311. [2] *Ibid.*, p. 296.

INGESTION OF FAT.

While it was relatively easy in this research to obtain subjects that could eat large quantities of protein and especially of carbohydrates, it was difficult to obtain those who could take large amounts of pure or approximately pure fat. In only one experiment, therefore, was an attempt made to give olive oil, this being in the form of a mayonnaise dressing. The results of the experiment have been reported in considerable detail in a previous section (see pages 63 *et seq.*). The earliest experiments with a predominatingly fat diet were made with cream, which was palatable and could be taken with relative ease. It was not, however, a pure fat, as it contained measurable amounts of protein and lactose. Another diet employed was butter and potato chips. This again was not a pure fat diet, as the potato chips, which were used more particularly as a vehicle for the butter, contained a certain amount of starch in combination with a considerable amount of fat. Aside from the single experiment with mayonnaise, we were obliged to content ourselves with these two imperfect fat diets.

STATISTICS OF EXPERIMENTS.

The experiments with a fat diet included 1 experiment with olive oil taken in mayonnaise, 7 experiments with cream, and 7 experiments with butter and potato chips. The metabolism was determined in all cases with the respiration calorimeter. The experiments in 1906 and 1907 were made in Middletown (see tables 184 to 186 and 191 to 194), while those in 1910 were carried out with the chair calorimeter in Boston (see tables 187 to 190 and 195 to 197). In the Middletown experiments the basal values used were obtained on some other than the experimental day, and the measurements were made in 2-hour periods. In the Boston experiments the basal values were obtained on the same day, immediately preceding the experiments with a fat diet, and the measurements were made in 1-hour periods. Data not included in the tables or discussion of the experiments are given in the following paragraphs:

A. H. M., 7 a. m., December 3, to 7 a. m., December 6, 1906.—Night before experiment was spent in calorimeter chamber; slept most of time; but little restlessness. At beginning of first fasting day, urinated, dressed, and assisted in weighing himself, then put bedding away and sat down; body-weight, 65.8 kilograms. Between 7^h24^m a. m. and 11^h03^m p. m. urinated 3 times, went to food aperture 8 times, took 3 strength tests, and drank water twice (total amount, 115 grams); slept sitting in chair about half hour in afternoon. Aside from some further slight activity, sat in chair quietly reading, writing, or idle until going to bed at 11^h03^m p. m. Awoke at 4 a. m., December 4; did not sleep soundly afterward.

At 7 a. m., December 4, rose, urinated, and dressed, then weighed himself; body-weight, 64.6 kilograms. Activity during second fasting day somewhat

less than on preceding day, as he lay on bed from 1^h06^m p. m. to 7^h02^m p. m. and again from 7^h30^m p. m. until he went to bed at 11^h02^m p. m. Between 7^h17^m a. m. and 11^h02^m p. m., urinated 3 times, went to food aperture 4 times, took 2 strength tests, and drank water twice (total amount, 186 grams). Aside from this activity, sat quietly in chair, for most part reading, writing, or idle. Restless during night, probably due to sleeping so much day before. Body-temperature rose during night somewhat higher than previous night.

At 7 a. m., December 5, rose, urinated, and dressed, then weighed himself; body-weight, 63.4 kilograms. Between 7 a. m. and 11^h02^m p. m., went to food aperture 14 times, drank water 8 times (total amount, 990 grams), took 3 strength tests, defecated at 12^h30^m p. m., and urinated twice in addition to urinating at 7 a. m. Food eaten slowly between 9^h06^m and 9^h48^m a. m. Slept few minutes about 2^h30^m p. m. and seemed drowsy about 8 p. m. Rest of time sat quietly in chair, reading, writing, or idle. Undressed and went to bed at 11^h02^m p. m.; awoke at 4 a. m., December 6, but soon went to sleep and slept soundly remainder of night. Pulse and respiration rates quickened at beginning of food day; pulse rate at times irregular on this day. Pulse rate for first day, 55; second day, 59; food day, 66. Respiration rate first day, 18; second day, 18; food day, 21.

A. L. L., 8^h30^m a. m. to 4^h30^m p. m., March 27, 1906. 68.4 kilograms.—Urinated 7^h18^m a. m., 12^h33^m and 4^h45^m p. m. Very quiet, reading most of time; sleepy last half hour. Body-temperature: 36.69°, 36.40°, 36.30°, 36.60°, 36.54° C. Pulse rate, 60; respiration rate, 19.

H. R. D., 8^h36^m a. m. to 4^h36^m p. m., March 28, 1906. 58.9 kilograms.—Urinated at 7^h15^m, 10^h47^m a. m., 2^h40^m, and 4^h50^m p. m. Read about two-thirds of experimental period and also made notes; occasionally drowsy, falling asleep twice. Cream did not inconvenience subject except for half hour, about 2 hours after experiment began. Body-temperature: 36.84°, 36.64°, 36.67°, 36.67°, 36.84° C. Pulse rate, 68; respiration rate, 19.

A. H. M., 8^h30^m a. m. to 4^h30^m p. m., April 5, 1906. 66.9 kilograms.—Took enema before entering calorimeter chamber; slight desire to defecate a half hour after drinking cream, which soon passed away. Somewhat restless for short time, but afterwards sat quietly reading; little sleepy in latter part of morning. Urinated 4^h32^m p. m. Body-temperature: 36.44°, 36.41°, 36.36°, 36.25°, 36.25° C. Pulse rate, 61; respiration rate, 19.

J. J. C., 9^h21^m a. m. to 3^h21^m p. m., March 22, 1910. 64.3 kilograms. 2 basal periods.—Urinated 7 a. m., 11^h21^m a. m. and 3^h31^m p. m. Asleep in second basal period (at 10^h53^m a. m.) and in first and second food periods (12^h08^m to 12^h20^m p. m. and 1^h08^m to 1^h20^m p. m.). In basal periods more or less restless; moving head and shoulders considerably; was asked to sit more quietly. After cream, more quiet, also more sleepy, having to be awakened. Basal periods: pulse rate, 64; respiration rate, 20. After cream: pulse rate 69; respiration rate, 20.

D. J. M., 9^h33^m a. m. to 1^h33^m p. m., March 23, 1910. 58.4 kilograms. 2 basal periods.—Urinated and defecated at 7^h50^m a. m. Telephoned considerably during experiment; drank water at 12^h52^m p. m. (200 grams). Asleep at beginning of second basal period (10^h36^m a. m.) and of second food period (12^h35^m p. m.). Basal periods: pulse rate, 68; respiration rate, 19. After cream: pulse rate, 72; respiration rate, 19. Nitrogen in urine per hour 6^h45^m a. m. to 7^h50^m a. m., 0.55 gram.

D. J. M., 9^h37^m a. m. to 2^h37^m p. m., June 3, 1910. 57.8 kilograms. 2 basal periods.—Defecated at 8^h23^m a. m.; urinated at 11^h02^m a. m., 1^h53^m and 2^h45^m p. m. Drank water at 10^h50^m a. m. (35 grams). Basal periods: body-temperature, 36.74°, 36.65°, 36.66° C.; pulse rate, 63; respiration rate, 17. After

cream: body-temperature, 36.69°, 36.76°, 36.77° C.; pulse rate, 69; respiration rate, 18.

D. J. M., 9h21m a. m. to 3h21m p. m., June 7, 1910. 58.2 kilograms. 2 basal periods.—Urinated 7h50m, 11h25m a. m. and 3h30m p. m. Drank water at 2h05m p. m. (53 grams). Basal periods: pulse rate, 62; respiration rate, 19. After cream: pulse rate, 66; respiration rate, 19.

E. H. B., 9h07m a. m. to 3h07m p. m., March 19, 1907. 72.9 kilograms.—Took enema and urinated about 7h15m a. m.; about 2 o'clock some desire to defecate, which later passed away. Drank water every period (total amount, 693 grams). Reading most of time; activity slight except in last period. Perspired about 15 minutes about 2h30m p. m.; was restless, and complained of feeling very warm; suffered from pain in abdomen, which shortly became acute; temperature and pulse rate rose; experiment concluded at end of third period. Body temperature, 37.57°, 37.76°, 37.81°, 38.10° C. Pulse rate, first period, 85; second period, 73; third period, 80 (rose between 2h02m and 2h33m p. m. from 69 to 91). Respiration rate, 21.

A. H. M., 9h34m a. m. to 5h34m p. m., March 25, 1907. 66.3 kilograms.—Urinated 7h15m a. m. after enema; attempted to urinate at 11h41m a. m.; passed urine at 1h34m p. m. and 5h41m p. m. Slightly nauseated while eating food. Some difficulty in adjusting chair, which necessitated considerable activity for a few minutes at beginning of first period. Drank water at 9h45m, 11h40m, 11h54m a. m., 1h42m p. m. (total amount, 693 grams). Somewhat restless throughout first two periods; idle much of time, or reading. Pulse rate, 73; respiration rate, 21.

A. H. M., 8h57m a. m. to 4h57m p. m., May 15, 1907. 65.5 kilograms.—Took enema about 7h10m a. m.; urinated at 6 a. m., 11h04m a. m., 5h06m p. m. Drank water at beginning of first period, 12h45m p. m., and 1h25m p. m. (total amount, 243 grams). Drowsy at first, then read and made notes for about half of remaining time. Body-temperature: 37.07°, 36.84°, 37.02°, 36.83°, 36.87° C. Pulse rate, 69; respiration rate, 19.

A. W. W., 8h42m a. m. to 4h42m p. m., April 25, 1907. 58.5 kilograms.—Urinated 7h10m a. m. (after enema), 10h46m a. m., 12h47m and 4h50m p. m. Drank water at beginning of each period (324 grams in all). Body-temperature: 36.58°, 36.65°, 36.89°, 36.94°, 36.97° C. Pulse rate, 65; respiration rate, 21.

J. J. C., 9h30m a. m. to 4h30m p. m., March 12, 1910. 63.7 kilograms. 2 basal periods.—Urinated 7 a. m., 9h38m a. m., and 4h42m p. m. Slept from 2h16m p. m. to 2h40m p. m. During last period was restless and telephoned to know how soon experiment would be over, as he was tired of sitting still. At 2h49m p. m., complained of cold and wrapped blanket around shoulders. Basal periods: body-temperature, 37.32°, 37.08°, 37.18° C.; pulse rate, 67; respiration rate, 19. After food: body-temperature, 37.34°, 37.34°, 37.33°, 37.36°, 37.42° C.; pulse rate, 65; respiration rate, 18. Nitrogen in urine per hour 7 a. m. to 9h38m a. m., 0.14 gram.

L. E. E., 9h23m a. m. to 4h23m p. m., March 14, 1910. 59.8 kilograms. 2 basal periods.—High-carbohydrate supper night before. Urinated 8h05m, 9h23m a. m., 2h23m p. m. Drank water 11h45m a. m. (97 grams). In first two periods subject kept slipping down in chair, then raising himself to a more erect position; seemed to find it difficult to obtain an easy position; in urinating at 2h23m p. m., moved considerably, nearly getting out of chair. Asleep between 1h08m and 1h14m p. m. and also at 3h08m p. m.; at 3h28m p. m., restless. Basal periods: pulse rate, 60; respiration rate, 17. After food: pulse rate, 60; respiration rate, 17.

J. R., 8h49m a. m. to 3h49m p. m., March 21, 1910. 67.4 kilograms. 2 basal periods.—Took enema and urinated at 7h05m a. m., also at 3h58m p. m. Drank 68 grams water after eating. Basal periods: body-temperature, 37.50°, 37.57°, 37.63° C.; pulse rate, 70; respiration rate, 15. After food: body-temperature, 37.75°, 37.73°, 37.74°, 37.81°, 37.93° C.; pulse rate, 73; respiration rate, 14.

DISCUSSION OF EXPERIMENTS.

OLIVE OIL (MAYONNAISE).

The experiment with A. H. M., December 5 to 6, 1906, was fully discussed in a previous section in which the basal metabolism was considered. Although originally planned for a 24-hour experiment, it was soon apparent that the effect of ingesting oil could be found only by studying the results obtained in the periods immediately following the taking of the mayonnaise; hence the results of the experiment have also been computed on both the 12-hour and the 8-hour basis. These results are given in tables 19, 20, and 21.[1] From the figures given in these tables, one may conclude that the effect of olive oil upon the metabolism is slight.

CREAM.

A. L. L., March 27, 1906.—This was the initial experiment of a series in which the three subjects took essentially the same amount of cream. The details of the experiment are given in table 184. In the 341 grams of cream used only 5 per cent of the energy came from protein and 8

TABLE 184.—*A. L. L., March 27, 1906. Sitting.* (2-hour periods.)

Cream:
Amount, 341 grams;[2] nitrogen, 1.46 grams; total energy, 748 cals.
Fuel value: Total, 735 cals.; from protein, 5 p. ct.; from fat, 87 p. ct.; from carbohydrates, 8 p. ct.
Nitrogen in urine, 0.72 gram per 2 hours.[3]
Basal values (April 3 and 6, 1906): CO_2, 47 grams; O_2, 43 grams; heat, 145 cals.

Time elapsed since subject finished eating.	Carbon dioxide.		Oxygen.		Heat.	
	Total.	Increase.	Total.	Increase.	Total.	Increase.
	grams.	*grams.*	*grams.*	*grams.*	*cals.*	*cals.*
0 to 2 hours	59	12	44	1	167	22
2 to 4 hours	54	7	44	1	155	10
4 to 6 hours	52	5	44	1	169	24
6 to 8 hours	48	1	41	−2	146	1
Total	213	25	173	1	637	57

[1]See pp. 67 to 69. The results of the 24-hour experiment are given in table 14, p. 64.
[2]Also 10 grams lime water and 253 grams water, a total of 604 grams.
[3]Sample included amount for about 1½ hours without food preceding experiment.

per cent from carbohydrates. The basal value employed was the average of two values determined a week or more later. Following the ingestion of the cream, measurable increases in carbon-dioxide production and heat production were observed in the first three periods, with a value essentially basal in the fourth period. The measurements of the oxygen consumption showed practically no variations from the basal value. Apparently the ingestion of the cream affected only the carbon-dioxide production and heat production.

H. R. D., March 28, 1906.—Approximately the same amount of cream was used as in the preceding experiment, 399 grams being taken. The details of this experiment are given in table 185. An increment in carbon-dioxide production was found in all of the periods of the experiment, with an increase in oxygen consumption in the first two periods. The value for the increase in the oxygen in the first period is erroneous, as the respiratory quotient for this period was only 0.55. The results obtained from the measurement of the heat production were irregular, but gave positive increases, although the total increment was small.

TABLE 185.—*H. R. D., March 28, 1906. Sitting.* (2-hour periods.)

Cream:

Amount, 399 grams;[1] nitrogen, 1.71 grams; total energy, 875 cals.

Fuel value: Total, 860 cals.; from protein, 5 p. ct.; from fat, 87 p. ct.; from carbohydrates, 8 p. ct.

Nitrogen in urine, 0.76 gram per 2 hours.

Basal values (February 6 to April 20, 1906): CO_2, 47 grams; O_2, 42 grams; heat, 146 cals.

Time elapsed since subject finished eating.	Carbon dioxide.		Oxygen.		Heat.	
	Total.	Increase.	Total.	Increase.	Total.	Increase.
	grams.	*grams.*	*grams.*	*grams.*	*cals.*	*cals.*
0 to 2 hours	52	5	68	....	155	9
2 to 4 hours	50	3	47	5	151	5
4 to 6 hours	49	2	43	1	146	0
6 to 8 hours	50	3	44	2	150	4
Total	201	13	202	....	602	18

[1]Also 9 grams lime-water and 194 grams water, a total of 602 grams.

A. H. M., April 5, 1906.—The subject took 345 grams of cream before this experiment. The basal value used was the average of two values determined approximately 7 weeks before. According to the results given in table 186, increments in the three factors of metabolism were observed in the first and second periods; approximately basal values were obtained in the third period. From this and the two preceding experiments, it is evident that the ingestion of cream had a positive influence upon the metabolism.

TABLE 186.—*A. H. M., April 5, 1906. Sitting.* (2-hour periods.)

Cream:
Amount, 345 grams;[1] nitrogen, 1.44 grams; total energy, 779 cals.
Fuel value: Total, 766 cals.; from protein, 5 p. ct.; from fat, 87 p. ct.; from carbohydrates 8 p. ct.
Basal values (February 12 and 14, 1906): CO_2, 45 grams; O_2, 40 grams; heat, 142 cals.

Time elapsed since subject finished eating.	Carbon dioxide.		Oxygen.		Heat.	
	Total.	Increase.	Total.	Increase.	Total.	Increase.
	grams.	*grams.*	*grams.*	*grams.*	*cals.*	*cals.*
0 to 2 hours	55	10	46	6	190	48
2 to 4 hours	51	6	49	9	161	19
4 to 6 hours	46	1	40	0	145	3
6 to 8 hours	46	1	43	3	145	3
Total	198	18	178	18	641	73

[1]Also 6 grams lime-water and 246 grams water, a total of 597 grams.

J. J. C., March 22, 1910.—The details of the first experiment in Boston with cream are given in table 187. A larger amount of cream was taken by this subject than by the subjects of the Middletown experiments, the amount being 445 grams. In the first hour no increment was obtained for any one of the three factors. Slight increases in the carbon-dioxide production and oxygen consumption were observed in the 3 following hours but the values for heat production were invariably below the basal value. There was a slight increase in the pulse rate during the two middle periods. At first sight these results would

TABLE 187.—*J. J. C., March 22, 1910. Sitting.* (1-hour periods.)

Cream:
Amount, 445 grams; nitrogen, 1.74 grams; total energy, 1,377 cals.
Fuel value: Total, 1,362 cals.; from protein, 3 p. ct.; from fat, 91 p. ct.; from carbohydrates, 6 p. ct.
Nitrogen in urine, 0.64 gram per hour.
Basal values (March 22, 1910): CO_2, 25 grams; O_2, 22.5 grams; heat,[1] 83 cals.; respiratory quotient, 0.81. Nitrogen in urine, 0.23 gram per hour.

Time elapsed since subject finished eating.	Carbon dioxide.		Oxygen.		Heat.[1]		Respiratory quotient.
	Total.	Increase.	Total.	Increase.	Total.	Increase.	
	grams.	*grams.*	*grams.*	*grams.*	*cals.*	*cals.*	
0 to 1 hour[2]	25.0	0.0	22.0	−0.5	80	−3	0.82
1 to 2 hours	27.0	2.0	24.0	1.5	74	−9	.81
2 to 3 hours	28.0	3.0	26.0	3.5	80	−3	.78
3 to 4 hours	28.5	3.5	25.0	2.5	78	−5	.83
Total	108.5	8.5	97.0	7.0	312	−20	....

[1]Heat eliminated corrected for change in body-weight, but not for change in body-temperature.
[2]Subject finished drinking cream 11 minutes after beginning of this period.

seem to confirm Gigon's[1] contention that the ingestion of a fat diet may result in a decreased katabolism. On the other hand, as the carbon-dioxide production and oxygen consumption showed a positive, though slight, increase and Gigon's measurements were based upon the gaseous metabolism and not upon direct measurements of the heat production, it is evident our observations can give no support to Gigon's theory.

D. J. M., March 23, June 3, and June 7, 1910.—In this series of 3 experiments, 221 grams, 398 grams, and 376 grams of cream, respectively, were taken. The subject was not especially satisfactory, as he was inclined to be restless; it is particularly unfortunate, therefore, that he should have been selected for this study in which so slight an effect upon the metabolism would be produced as with cream. Hence the three experiments can be treated only in a general way and discussion of the individual periods is unjustifiable. The results of the experiments are given in tables 188, 189, and 190. From an examination of the data it is seen that there was no positive increase in any of the factors measured in the experiment of March 23. In the experiment on June 3 there was a total increment of about 4 grams in carbon-dioxide production, 11 grams in oxygen consumption, and 20 calories in heat production. Similar increases in the first two factors are seen in the experiment of June 7, but not in heat production. The detailed pulse records (not given in the tables) show very little increase in the experiment of March 23, but in the experiment of June 3 there was a change from an average of 63 in the preliminary period to an average of 69 after food. A similar change in the pulse rate occurred in the experiment of June 7.

TABLE 188.—*D. J. M., March 23, 1910. Sitting.* (1-hour periods.)

Cream:

Amount, 221 grams; nitrogen, 0.85 gram; total energy, 673 cals.

Fuel value: Total, 666 cals.; from protein, 3 p. ct.; from fat, 91 p. ct.; from carbohydrates, 6 p. ct.

Nitrogen in urine, 0.40 gram per hour.[2]

Basal values (March 23, 1910): CO_2, 25.5 grams; O_2, 21.0 grams; heat,[3] 70 cals.; respiratory quotient, 0.87.

Time elapsed since subject finished eating.	Carbon dioxide.		Oxygen.		Heat.[3]		Respiratory quotient.
	Total.	Increase.	Total.	Increase.	Total.	Increase.	
	grams.	*grams.*	*grams.*	*grams.*	*cals.*	*cals.*	
0 to 1 hour[4]	25.5	0	21.0	0.0	68	−2	0.88
1 to 2 hours	25.5	0	22.0	1.0	73	3	.84
Total	51.0	0	43.0	1.0	141	1	....

[1]Gigon, Arch. f. d. ges. Physiol., 1911, **140,** p. 509.

[2]Sample included amount for 4 hours without food preceding experiment.

[3]Heat eliminated corrected for change in body-weight, but not for change in body-temperature.

[4]Subject finished eating 21 minutes after beginning of this period. The eating occupied 7 minutes.

TABLE 189.—*D. J. M., June 3, 1910. Sitting.* (1-hour periods.)

Cream:
Amount, 398 grams; nitrogen, 1.55 grams; total energy, 1,074 cals.
Fuel value: Total, 1,060 cals.; from protein, 4 p. ct.; from fat, 89 p. ct.; from carbohydrates, 7 p. ct.
Basal values (June 3, 1910): CO_2, 25 grams; O_2, 20.5 grams; heat, 76 cals.; respiratory quotient, 0.88. Nitrogen in urine, 0.49 gram per hour.

Time elapsed since subject finished eating.	Nitrogen in urine per hour.	Carbon dioxide.		Oxygen.		Heat.		Respiratory quotient.
		Total.	Increase.	Total.	Increase.	Total.	Increase.	
	gram.	*grams.*	*grams.*	*grams.*	*grams.*	*cals.*	*cals.*	
0 to 1 hour[1]...	0.49	25.5	0.5	22.5	2.0	88	12	0.83
1 to 2 hours...	.49	26.0	1.0	24.5	4.0	78	2	.76
2 to 3 hours...	.51	27.0	2.0	25.0	4.5	82	6	.78
Total....	...	78.5	3.5	72.0	10.5	248	20	....

[1]Subject finished eating 15 minutes after beginning of this period. The cream was taken quickly.

TABLE 190.—*D. J. M., June 7, 1910. Sitting.* (1-hour periods.)

Cream:
Amount, 376 grams; nitrogen, 1.35 grams; total energy, 1,257 cals.
Fuel value: Total, 1,245 cals.; from protein, 3 p. ct.; from fat, 92 p. ct.; from carbohydrates, 5 p. ct.
Nitrogen in urine, 0.43 gram per hour.
Basal values (June 7, 1910): CO_2, 26 grams; O_2, 21 grams; heat,[1] 80 cals.; respiratory quotient, 0.89. Nitrogen in urine, 0.45 gram per hour.

Time elapsed since subject finished eating.	Carbon dioxide.		Oxygen.		Heat.[1]		Respiratory quotient.
	Total.	Increase.	Total.	Increase.	Total.	Increase.	
	grams.	*grams.*	*grams.*	*grams.*	*cals.*	*cals.*	
0 to 1 hour[2]	27.5	1.5	22.0	1.0	78	−2	0.90
1 to 2 hours.....	28.5	2.5	25.5	4.5	80	0	.82
2 to 3 hours.....	27.5	1.5	25.0	4.0	81	1	.79
3 to 4 hours.....	26.5	.5	23.0	2.0	79	−1	.85
Total.....	110.0	6.0	95.5	11.5	318	−2	....

[1]Heat eliminated corrected for change in body-weight, but not for change in body-temperature.
[2]Subject finished eating 11 minutes after beginning of this period. The eating occupied 7 minutes.

BUTTER AND POTATO CHIPS.

Relatively large amounts of fat were ingested in the diet of butter and potato chips. The latter is a common food material in America and consists of thin slices of raw potato fried in deep fat. As a rule potato chips have a composition of approximately 5 per cent protein, 40 per cent fat, and 42 per cent carbohydrate, with a fuel value of 5.5 calories per gram. Details regarding the composition of those used in our study may be found in table 50.[1] It will be seen from these figures that the potato chips not only served as a vehicle for the butter,

[1]See p. 124.

but also supplied a considerable proportion of the energy in the form of fat. It was hoped that the subjects of the experiments would be able to take large amounts of butter with the potato chips, but unfortunately this was possible in only a few experiments.

E. H. B., March 19, 1907.—The subject of the first experiment with this diet was able to eat only 83 grams of butter with 233 grams of potato chips. The basal value selected for comparison is an average of values obtained in two experiments made a week or 10 days previous to the experiment with butter. The results of the experiment are given in table 191. Notable increases were obtained in the carbon-dioxide production for the three 2-hour periods after the taking of the food; considerable increments were also found for oxygen consumption and heat production. It may therefore be considered that the fat diet of butter and potato chips had a decided influence upon the metabolism. Although 22 per cent of the energy in the diet was derived from carbohydrates, it is hardly probable that the amount present played a very important part in the metabolism.

TABLE 191.—*E. H. B., March 19, 1907. Sitting.* (2-hour periods.)

Butter and potato chips:

Amounts, 83 grams butter, 233 grams potato chips; nitrogen, 2.18 grams; total energy, 1,943 cals.

Fuel value: Total, 1,924 cals.; from protein, 3 p. ct.; from fat, 75 p. ct.; from carbohydrates, 22 p. ct.

Basal values (March 7 and 13, 1907): CO_2, 58 grams; O_2, 48 grams; heat, 179 cals.

Time elapsed since subject finished eating.[1]	Carbon dioxide.		Oxygen.		Heat.[2]	
	Total.	Increase.	Total.	Increase.	Total.	Increase.
	grams.	*grams.*	*grams.*	*grams.*	*cals.*	*cals.*
1¼ to 3¼ hours	69	11	57	9	198	19
3¼ to 5¼ hours	71	13	58	10	195	16
5¼ to 7¼ hours	64	6	55	7	201	22
Total	204	30	170	26	594	57

[1]Subject ate food in about 30 minutes.

[2]Heat eliminated corrected for change in body-weight, but not for change in body-temperature.

A. H. M., March 25, 1907.—The largest amount of butter used in this series of experiments was taken by A. H. M., who was able to eat 243 grams with 211 grams of potato chips. The available energy of the food was over 3,000 calories. Of this energy, 85 per cent was derived from fat and but 13 per cent from carbohydrates. The basal value was obtained in two experiments two or three weeks previous to the experiment with butter. Positive increments of considerable magnitude were observed in the three factors of the metabolism with no indication of a return to the basal value at the end of the fourth

2-hour period (see table 192). The subject, who has always been considered very satisfactory, maintained approximately uniform muscular activity throughout the entire experiment. We may consider, therefore, that the increment measured is clearly due to the fat diet and that the ingestion of butter and potato chips in these proportions had a decided positive effect upon the metabolism.

TABLE 192.—*A. H. M., March 25, 1907. Sitting.* (2-hour periods.)

Butter and potato chips:

Amounts, 243 grams butter, 211 grams potato chips; nitrogen, 2.24 grams; total energy, 3,222 cals.

Fuel value: Total, 3,202 cals.; from protein, 2 p. ct.; from fat, 85 p. ct.; from carbohydrates, 13 p. ct.

Nitrogen in urine, 0.89 gram per 2 hours.[1]

Basal values (March 6 and 9, 1907): CO_2, 51 grams; O_2, 46 grams; heat, 164 cals.

Time elapsed since subject finished eating.[2]	Carbon dioxide.		Oxygen.		Heat.[3]	
	Total.	Increase.	Total.	Increase.	Total.	Increase.
	grams.	*grams.*	*grams.*	*grams.*	*cals.*	*cals.*
¼ to 2¼ hours	67	16	55	9	194	30
2¼ to 4¼ hours	63	12	52	6	197	33
4¼ to 6¼ hours	67	16	62	16	199	35
6¼ to 8¼ hours	64	13	55	9	191	27
Total	261	57	224	40	781	125

[1]Sample included amount for about 1½ hours preceding eating of food.

[2]Subject ate food in 37 minutes.

[3]Heat eliminated corrected for change in body-weight, but not for change in body-temperature.

A. H. M., May 15, 1907.—This second experiment was made with A. H. M. about 7 weeks later; the details are given in table 193. He was able to take only about half as much butter as in the previous experiment, with a proportionate amount of potato chips. The exact amounts taken were 113 grams of butter and 105 grams of potato chips. Even with this reduced amount of fat in the diet, there was a positive increment in carbon-dioxide production and heat production in the first two periods. The values obtained for oxygen consumption were erratic, the total effect being 10 grams less than the basal value. Since both carbon-dioxide production and heat production showed a positive increment, it is reasonable to conclude that this diet had a definite effect upon the metabolism. As the respiratory quotients were much higher than would be expected with a fat diet, it is probable that the determinations of the oxygen consumption were erroneous.

A. W. W., April 25, 1907.—The amount of butter eaten by this subject, 85 grams, was approximately the same as that taken by E. H. B., but the amount of potato chips was smaller, as he used but 104 grams or about the same amount as that taken by A. H. M. in his last experiment. The details of the experiment are given in table 194. The

increment in the metabolism is small in amount but is nevertheless distinctly positive, although the basal value for the heat production was reached in the third period and presumably in the same period for the carbon-dioxide production.

TABLE 193.—*A. H. M., May 15, 1907. Sitting.* (2-hour periods.)

Butter and potato chips:
Amounts, 113 grams butter, 105 grams potato chips; nitrogen, 1.11 grams; total energy, 1,512 cals.
Fuel value: Total, 1,503 cals.; from protein, 2 p. ct.; from fat, 85 p. ct.; from carbohydrates, 13 p. ct.
Basal values (March 6 and 9, 1907): CO_2, 51 grams; O_2, 46 grams; heat, 164 cals.

Time elapsed since subject finished eating.[1]	Nitrogen in urine per 2 hours.	Carbon dioxide.		Oxygen.		Heat.	
		Total.	Increase.	Total.	Increase.	Total.	Increase.
	grams.	*grams.*	*grams.*	*grams.*	*grams.*	*cals.*	*cals.*
¼ to 2¼ hours	[2]1.09	55	4	41	−5	172	8
2¼ to 4¼ hours	.90	60	9	47	1	184	20
4¼ to 6¼ hours	.90	50	−1	42	−4	161	−3
6¼ to 8¼ hours	.90	53	2	44	−2	167	3
Total	....	218	14	174	−10	684	28

[1]Subject ate food in 28 minutes.
[2]Sample included amount for about 2¼ hours preceding eating of food.

TABLE 194.—*A. W. W., April 25, 1907. Sitting.* (2-hour periods.)

Butter and potato chips:
Amounts, 85 grams butter, 104 grams potato chips; nitrogen, 1.05 grams; total energy, 1,285 cals.
Fuel value: Total, 1,276 cals.; from protein, 2 p. ct.; from fat, 82 p. ct.; from carbohydrates, 16 cals.
Basal values (March 15 and 21, 1907): CO_2, 50 grams; O_2, 41 grams; heat, 155 cals.

Time elapsed since subject finished eating.[1]	Nitrogen in urine per 2 hours.	Carbon dioxide.		Oxygen.		Heat.	
		Total.	Increase.	Total.	Increase.	Total.	Increase.
	gram.	*grams.*	*grams.*	*grams.*	*grams.*	*cals.*	*cals.*
1 to 3 hours	0.57	53	3	43	2	165	10
3 to 5 hours	.53	54	4	43	2	161	6
5 to 7 hours	.44	51	1	44	3	154	−1
7 to 9 hours	.44	51	1	42	1	155	0
Total	....	209	9	172	8	635	15

[1]Subject ate food in 26 minutes.

J. J. C., March 12, 1910.—The experiment on this date was the first of a supplementary series with the butter and potato chips diet carried out in Boston three years after the Middletown experiments. The subject took but 38 grams of butter and 91 grams of potato chips; the results obtained are given in table 195. Although the basal value was determined on the same day as the values after food, and the general trend of the results was similar to that of the results obtained in the previous experiments, we do not feel justified in laying great emphasis

upon the data, owing to the general irregularity in muscular repose shown by this subject, especially in the sitting position. The experiment may be said, therefore, to give incomplete evidence as to the increment in the metabolism due to a predominatingly fat diet.

TABLE 195.—*J. J. C., March 12, 1910. Sitting.* (1-hour periods.)

Butter and potato chips:

Amounts, 38 grams butter, 91 grams potato chips; nitrogen, 0.76 gram; total energy, 798 cals.

Fuel value: Total, 791 cals.; from protein, 2 p. ct.; from fat, 79 p. ct.; from carbohydrates, 19 p. ct.

Nitrogen in urine, 0.30 gram per hour.[1]

Basal values (March 12, 1910): CO_2, 24 grams; O_2, 20.5 grams; heat, 75 cals.; respiratory quotient, 0.86. Nitrogen in urine, 0.14 gram per hour.

Time elapsed since subject finished eating.	Carbon dioxide.		Oxygen.		Heat.		Respiratory quotient.
	Total.	Increase.	Total.	Increase.	Total.	Increase.	
	grams.	*grams.*	*grams.*	*grams.*	*cals.*	*cals.*	
0 to 1 hour[2]	26.0	2.0	24.0	3.5	87	12	0.79
1 to 2 hours	27.0	3.0	25.5	5.0	79	4	.78
2 to 3 hours	27.5	3.5	26.5	6.0	78	3	.75
3 to 4 hours	25.5	1.5	20.5	0.0	71	−4	.91
4 to 5 hours	25.0	1.0	23.0	2.5	74	−1	.79
Total	131.0	11.0	119.5	17.0	389	14	....

[1]Sample included amount for about 2 hours preceding eating of food.

[2]Subject finished eating 22 minutes after beginning of this period. The eating occupied 16 minutes.

L. E. E., March 14, 1910.—A larger amount of butter was taken in this experiment than in the preceding experiment, 92 grams being eaten with 114 grams of potato chips. The detailed results are given in table 196. Although L. E. E. was a trained observer on the staff of the Nutrition Laboratory and accustomed to remaining very quiet, he was in this experiment distinctly restless. The increment in carbon-dioxide production was found in the first and third periods; the values for oxygen consumption and heat production were also irregular. For some as yet unexplained reason, the metabolism in the second and fourth periods was shown to be basal by all three factors. The total increment for the carbon-dioxide production was 6 grams, for the oxygen consumption 13 grams, and for the heat production 36 calories, thus confirming the evidence of the experiments previously discussed that the ingestion of a predominatingly fat diet has a positive effect upon the metabolism.

J. R., March 21, 1910.—After the ingestion of 95 grams of butter and 92 grams of potato chips, slight increments were found in carbon-dioxide production throughout the 5 hours of the experiment and in most of the periods for heat production, with somewhat large increments in oxygen consumption. The results of the experiment, which are given in detail in table 197, thus supply further proof as to the

stimulating effect of a fat diet upon the metabolism. In the three experiments with the Boston calorimeter the last one with J. R. is the only one in which there was a noticeable increase in the pulse rate after the taking of food. The change was from 70 in the preliminary period to 73 after food.

TABLE 196.—*L. E. E., March 14, 1910. Sitting.* (1-hour periods.)

Butter and potato chips:

Amounts, 92 grams butter, 114 grams potato chips; nitrogen, 0.69 gram; total energy, 1,518 cals.

Fuel value: Total, 1,512 cals.; from protein, 1 p. ct.; from fat, 86 p. ct.; from carbohydrates, 13 p. ct.

Nitrogen in urine, 0.47 gram per hour (in first three periods).[1]

Basal values (March 14, 1910): CO_2, 27 grams; O_2, 22 grams; heat,[2] 70 cals.; respiratory quotient, 0.88. Nitrogen in urine, 0.56 gram per hour.

Time elapsed since subject finished eating.	Carbon dioxide.		Oxygen.		Heat.[2]		Respiratory quotient.
	Total.	Increase.	Total.	Increase.	Total.	Increase.	
	grams.	*grams.*	*grams.*	*grams.*	*cals.*	*cals.*	
0 to 1 hour[3]	30.5	3.5	26.0	4.0	85	15	0.85
1 to 2 hours	27.0	0.0	21.5	−0.5	67	−3	.92
2 to 3 hours	29.0	2.0	26.5	4.5	83	13	.79
3 to 4 hours	27.0	0.0	22.5	0.5	71	1	.88
4 to 5 hours	27.5	0.5	26.5	4.5	80	10	.76
Total	141.0	6.0	123.0	13.0	386	36	....

[1]Sample included amount for about 2 hours preceding the eating of food.

[2]Heat eliminated corrected for change in body-weight, but not for change in body-temperature.

[3]Subject finished eating 20 minutes after beginning of this period. The eating occupied 16 minutes.

TABLE 197.—*J. R., March 21, 1910. Sitting.* (1-hour periods.)

Butter and potato chips:

Amounts, 95 grams butter, 92 grams potato chips; nitrogen, 0.85 gram; total energy, 1,273 cals.

Fuel value: Total, 1,266 cals.; from protein, 2 p. ct.; from fat, 87 p. ct.; from carbohydrates, 11 p. ct.

Nitrogen in urine, 0.36 gram per hour.[1]

Basal values (March 21, 1910): CO_2, 26 grams; O_2, 21 grams; heat, 80 cals.; respiratory quotient, 0.89. Nitrogen in urine, 0.35 gram per hour.

Time elapsed since subject finished eating.	Carbon dioxide.		Oxygen.		Heat.		Respiratory quotient.
	Total.	Increase.	Total.	Increase.	Total.	Increase.	
	grams.	*grams.*	*grams.*	*grams.*	*cals.*	*cals.*	
0 to 1 hour[2]	28.0	2.0	24.5	3.5	85	5	0.84
1 to 2 hours	28.5	2.5	24.5	3.5	78	−2	.85
2 to 3 hours	28.0	2.0	24.5	3.5	83	3	.83
3 to 4 hours	27.5	1.5	22.0	1.0	81	1	.91
4 to 5 hours	28.0	2.0	26.5	5.5	84	4	.77
Total	140.0	10.0	122.0	17.0	411	11	....

[1]Sample included amount for about 3¾ hours without food preceding experiment.

[2]Subject finished eating 17 minutes after beginning of this period. The eating occupied 9 minutes.

CONCLUSIONS REGARDING EFFECT OF INGESTION OF FAT.

Although the experiments in this series can hardly be considered as ideal, being open to the criticisms raised in their discussion, yet the preponderance of evidence clearly shows that the ingestion of fat in the form of cream, or butter with potato chips, has a positive influence upon the metabolism. This is not in accordance with the results of Koraen,[1] who found no increase in the metabolism after the ingestion of about 66 grams of fat. Aside from a few experiments in which a depression in the metabolism below the basal value was found in the latter part of the experimental period, we obtained no evidence supporting the general view of Gigon that the ingestion of fat results in a depression of the metabolism (see page 40). Gigon's most interesting and suggestive explanation of his experiments, namely, that the ingestion of a fat diet (olive oil) caused a depression of the digestive activity which is present even in the post-absorptive condition, finds no support in the results of our experiments. It should be borne in mind that Gigon used a pure fat, while all of our experiments were carried out with materials containing a certain proportion of other nutrients. It is difficult, however, to believe that the starch in the potato chips or the small amount of protein and lactose in the cream could have counterbalanced the effect observed by Gigon. We are inclined to consider that the depression in the metabolism reported by him was more apparent than real and that his findings are due to the faulty use of a basal value, determined a long time before the experiments were made. By the use of this value he assumed a constancy in basal metabolism which, while justifiable when severe muscular work is to be performed, is hardly permissible when small increments in the metabolism are to be expected, such as those following the ingestion of small amounts of food or even large amounts of fat.[2]

We may therefore conclude that the ingestion of fat produces a positive increment in the metabolism. Although the increment is considerably less than that observed with an equivalent amount of energy in either carbohydrate or protein, it is nevertheless a factor that must not be neglected in a consideration of the influence of the ingestion of food upon the metabolism. We are in full accord with Gigon in believing that a study of the effect on the metabolism of ingesting pure fat is highly desirable and regret that more experiments with olive oil or other pure fats were not included in our series.

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[1]Koraen, Skand. Arch. f. Physiol., 1901, **11**, p. 176. See, also, p. 32 of this publication.

[2]Personal acquaintance with Professor Gigon and a full appreciation of his high scientific conceptions of the importanee of physiologieal research have led us to attempt to communicate with him personally regarding the adverse criticisms which we have felt it necessary to make in this report. While an aeknowledgment of the receipt of the letter has been made, he states that it has been impossible for him as yet to take up in detail any of the criticisms which we raise, although he promises to send a letter to us shortly. Undoubtedly war conditions have made it impracticable for him to do this. It is a matter of great regret to us that we have been obliged to go to press without personal information regarding the criticisms here raised, so that if we are in error or have misinterpreted his attitude we might modify our expressions in such way as to fit the case more exactly.

INGESTION OF PREDOMINATINGLY PROTEIN DIETS.

No single nutrient, when ingested, produces so great an effect upon the metabolism as protein does. In fact, the earlier observations, particularly those made by Rubner and Magnus-Levy with dogs and man, appeared to show that protein was the only nutrient which measurably increased the metabolism. At the time of beginning our study on the effect of food upon the metabolism, the varieties of pure protein available were relatively limited. Accordingly the largest number of experiments were made with beefsteak, for though this food material was not a pure protein, it was palatable and easily obtained. Furthermore, as the beefsteak given the subject was freed from all visible fat, it was assumed that the amount of fat ingested would play but a small part in the metabolism. In a number of the beefsteak experiments small amounts of bread or potato chips were also taken. In some of the observations approximately pure protein materials were used, these being gluten, plasmon, and in the later experiments in Boston, glidine. The gluten and plasmon were both taken with skim milk.

In the experiments with relatively pure protein and in a large proportion of the beefsteak experiments the observations were made with the calorimeter. While these experiments do not by any means fulfill the demands of the technique at the present time, they do represent the first attempt with man to determine by direct calorimetry the influence upon the metabolism of the ingestion of protein; consequently they are discussed in some detail. One defect in the plan of experimenting for all of the Middletown calorimeter experiments and for the majority of the Boston calorimeter experiments is the fact that the basal values and the values after the ingestion of protein were not determined on the same day.

Although the experiments with gluten and skim milk and plasmon and skim milk were made in 1906, while those with beefsteak were not begun until 1907, it seems desirable to consider first the data with the single food materials, especially as so large a number of observations were made with beefsteak.

BEEFSTEAK.

MIDDLETOWN CALORIMETER EXPERIMENTS.

The four Middletown experiments, which were made with but two subjects, are best discussed according to the amounts of food ingested, as they were planned for comparison purposes. In the first pair of experiments, those with A. H. M. on April 5, 1907, and A. W. W. on April 6, 1907, a large amount of beefsteak was taken, the measurements of the metabolism beginning about an hour after the subject had finished eating. In the second set of observations with the same sub-

jects on May 24 and 25, 1907, the amount of food used was about half that taken in the earlier series; the metabolism measurements began approximately 15 minutes after the eating of the beefsteak. In all of these experiments the periods were 2 hours long. Statistical data regarding the experiments, not included in the tables or the discussion, are as follows:

A. H. M., 9h29m a. m. to 5h29m p. m., April 5, 1907. 65.9 kilograms.—Took enema without result; drank water 9h37m a. m., 11h34m a. m., 12h13m p. m., 1h32m p. m. (total amount, 325 grams). Urinated 7h15m, 9h35m, 11h31m a. m., 1h32m, 3h30, 5h29m p. m.; slight desire to defecate in later periods. First two periods very quiet, reading most of time; in last two periods somewhat more active but still comparatively quiet; read but little in these periods. Body-temperature: 36.87°, 36.76°, 36.70°, 36.82°, 36.85° C. Pulse rate, 64; respiration rate, 18. Nitrogen in urine per 2 hours 7h15m a. m. to 9h35m a. m., 3.23 grams.

A. W. W., 9h08m a. m. to 5h08m p. m., April 6, 1907. 58.8 kilograms.—Enema at 7h10m a. m., feeling of heaviness and fullness after eating; drowsy during first part of experiment; studied first three periods, translating with use of vocabulary, with consequently more minor activity than usual; fourth period very quiet; middle of experiment, also throughout last period, felt warm and perspired. Drank water at beginning of every period (846 grams in all); urinated 8h09m a. m. and every period of experiment. Body-temperature: 36.77°, 36.70°, 36.69°, 36.79°, 36.79° C. Pulse rate, 66; respiration rate, 21.

A. H. M., 9h24m a. m. to 5h24m p. m., May 24, 1907. 65.9 kilograms.—Enema at 7h15m a. m. without result. Quiet in experiment; read greater part of time; idle last hour. Drank water before experiment (175 grams); at end of first period (31 grams). Tired at end of experiment. Urinated 7h10m and 11h30m a. m., 3h30m and 5h50m p. m. Body-temperature: 36.40°, 36.39°, 36.40°, 36.12°, 36.30° C. Pulse rate, 63; respiration rate, 18.

A. W. W., 8h17m a. m. to 4h17m p. m., May 25, 1907. 56.7 kilograms.—Very quiet throughout experiment; urinated 6h30m a. m. and in each of three last periods; drank water at beginning of every period (787 grams in all). Pulse rate, 64; respiration rate, 19.

DISCUSSION OF EXPERIMENTS.

A. H. M., April 5, 1907.—The subject consumed 777 grams of beefsteak in 1¼ hours; the nitrogen content of the food was 35.68 grams. The basal values used for comparison were obtained from two experiments made about a month previous to the experiment with beefsteak. This man had been used for a large number of experiments and was usually very quiet and satisfactory in every way. While there was not complete muscular repose throughout the experiment, the subject sat quietly in a chair, reading most of the time. The urine was collected in periods of 2 hours for the purpose of obtaining an indication of the course of the nitrogen excretion.

The results of the experiment are given in table 198 and show a striking increment in all the factors of metabolism. The carbon-dioxide production increased 12 to 20 grams, the oxygen consumption 8 to 16 grams, and the heat production 29 to 41 calories. The res-

piratory quotients remained relatively constant throughout the whole experimental period, averaging 0.85. Both carbon-dioxide production and oxygen consumption showed a maximum increase in the first 2-hour period, while that for heat production occurred in the third period. The maximum percentage increases were 39 per cent for the

TABLE 198.—*A. H. M., April 5, 1907. Silling.* (2-hour periods.)

Beefsteak:
Amount, 777 grams; nitrogen, 35.68 grams; total energy, 1,617 cals.
Fuel value: Total, 1,305 cals.; from protein, 70 p. ct.; from fat, 30 p. ct.
Basal values (March 6 and 9, 1907): CO_2, 51 grams; O_2, 46 grams; heat, 164 cals.

Time elapsed since subject finished eating.[1]	Nitrogen in urine per 2 hours.	Carbon dioxide.			Oxygen.			Heat.			Respiratory quotient.
		Total.	Increase.		Total.	Increase.		Total.	Increase.		
			Total.	Per cent.		Total.	Per cent.		Total.	Per cent.	
	grams.	*grams.*	*grams.*		*grams.*	*grams.*		*cals.*	*cals.*		
1 to 3 hours	4.00	71	20	39	62	16	35	195	31	19	0.84
3 to 5 hours	2.08	64	13	25	54	8	17	193	29	18	.87
5 to 7 hours	2.38	69	18	35	59	13	28	205	41	25	.85
7 to 9 hours	3.03	63	12	24	55	9	20	199	35	21	.83
Total..	....	267	63	31	230	46	25	792	136	21	....

[1]Subject ate beefsteak in $1\frac{1}{4}$ hours.

carbon-dioxide production, 35 per cent for the oxygen consumption, and 25 per cent for the heat production. As there was a large increment in the last period, it is quite clear that the influence of the beefsteak on the metabolism had not ceased at the end of the experiment. The computation of the total increment and the total percentage increase can therefore have but little quantitative value, but as the figures have a general interest they are given in table 198. There was a total increment of 63 grams in carbon-dioxide production, 46 grams in oxygen consumption, and 136 calories in heat production.

A. W. W., April 6, 1907.—Essentially the same amount of food was taken in this experiment as in that on the preceding day with A. H. M., *i. e.*, 755 grams, with a total nitrogen content of 34.67 grams. The results, including the data for the nitrogen excretion, are given in table 199. The basal values used were averages of the results obtained in two experiments made from 2 to 3 weeks previous to the experiment with beefsteak. A noticeable increase in carbon-dioxide production occurs in all periods, the maximum amount being obtained in the third period. The maximum oxygen consumption appeared in the second period, while the maximum heat production was found in the fourth period. The course of the respiratory quotient was somewhat irregular. Since there are material increases in the fourth period, it is evident that here again we have not obtained the total effect of the

TABLE 199.—*A. W. W., April 6, 1907. Sitting.* (2-hour periods.)

Beefsteak:
Amount, 755 grams; nitrogen, 34.67 grams; total energy, 1,571 cals.
Fuel value: Total, 1,268 cals.; from protein, 70 p. ct.; from fat, 30 p. ct.
Basal values (March 15 and 21, 1907): CO_2, 50 grams; O_2, 41 grams; heat, 155 cals.

Time elapsed since subject finished eating.[1]	Nitrogen in urine per 2 hours.	Carbon dioxide.			Oxygen.			Heat.			Respiratory quotient.
		Total.	Increase.		Total.	Increase.		Total.	Increase.		
			Total.	Per cent.		Total.	Per cent.		Total.	Per cent.	
	grams.	*grams.*	*grams.*		*grams.*	*grams.*		*cals.*	*cals.*		
1 to 3 hours	[2]2.08	60	10	20	47	6	15	152	−3	−2	0.93
3 to 5 hours	2.52	62	12	24	57	16	39	181	26	17	.79
5 to 7 hours	3.11	63	13	26	52	11	27	187	32	21	.88
7 to 9 hours	3.65	60	10	20	53	12	29	192	37	24	.82
Total..	....	245	45	23	209	45	27	712	92	15	....

[1]Subject ate beefsteak in 54 minutes.
[2]Sample included amount for about 1 hour following the eating of beefsteak.

food upon the metabolism in the 8 hours of the experimental period, and the experiment is therefore incomplete in this respect. It was of course possible to have made the experiment of 24 hours' duration, subdividing it into three 8-hour periods, but the main purpose of our experimenting was to study the maximum effect in the earlier stages of digestion, and the data are sufficient for this purpose. Thus we find that the maximum increment for carbon-dioxide production was 26 per cent, for oxygen consumption 39 per cent, and for heat production 24 per cent. One anomalous value appears in the results—that is, the slightly negative value found for heat production in the first period. This may be taken as essentially the basal value, although undoubtedly an error in direct calorimetry may have accounted for the fact that no increment was noted. The general picture shown in these results is not unlike that of the preceding experiment, namely, a decided increase in all of the factors of the metabolism. The fact that the high increments continued even into the last period indicates that the effect of food ingestion had not begun to decrease at the end of the experiment.

A. H. M., May 24, 1907.—Approximately half the amount of beefsteak used in the experiment with this subject on April 5, 1907, was taken in the second experiment, the amount in this case being 384 grams, with a nitrogen content of 17.63 grams. The basal values used in the first experiment were likewise employed here. The data regarding metabolism, together with those for nitrogen excretion, are given in table 200. An increase in carbon-dioxide production, oxygen consumption, and heat production occurred in the first three periods, with a return to the basal metabolism in the fourth period. We doubtless have here, therefore, the total effect of the ingestion

of this amount of beefsteak. The maximum increment occurred in the second period with all three factors, the percentage maximum for carbon-dioxide production being 27 per cent, for oxygen consumption 20 per cent, and for heat production 16 per cent.

TABLE 200.—*A. H. M., May 24, 1907. Sitting.* (2-hour periods.)

Beefsteak:
Amount, 384 grams; nitrogen, 17.63 grams; total energy, 799 cals.
Fuel value: Total, 644 cals.; from protein, 70 p. ct.; from fat, 30 p. ct.
Basal values (March 6 and 9, 1907): CO_2, 51 grams; O_2, 46 grams; heat, 164 cals.

Time elapsed since subject finished eating.[1]	Nitrogen in urine per 2 hours.	Carbon dioxide.		Oxygen.		Heat.[2]		Respiratory quotient.
		Total.	Increase.	Total.	Increase.	Total.	Increase.	
	grams.	*grams.*	*grams.*	*grams.*	*grams.*	*cals.*	*cals.*	
¼ to 2¼ hours	[3]1.61	60	9	48	2	188	24	0.91
2¼ to 4¼ hours	2.45	65	14	55	9	191	27	.85
4¼ to 6¼ hours	2.45	55	4	52	6	183	19	.78
6¼ to 8¼ hours	1.75	52	1	46	0	164	0	.82
Total...	....	232	28	201	17	726	70	....

[1]Subject ate beefsteak in 1½ hours.
[2]Heat eliminated corrected for change in body-weight, but not for change in body-temperature.
[3]Sample included amount for about ½ hour without food and for 1¾ hours with food preceding this period.

A. W. W., May 25, 1907.—Although made with a different subject, this is essentially a duplicate of the experiment on May 24, 1907, as the amount of beefsteak ingested (373 grams) is practically the same in both experiments and approximately one-half the amount eaten by A. W. W. in the experiment on April 6, 1907. The nitrogen content of the food was 18.62 grams. The results are given in table 201, and show the same general picture as the data given in table 200, *i. e.*, an increment in the first three periods with a return to the basal metabolism in the fourth period. A singular fact to be noted is that the maximum effect for all three factors was observed in the third period, although this immediately preceded the return to the basal level. The total increment in carbon-dioxide production was 20 grams, in oxygen consumption 32 grams, and in heat production 45 calories. The total increment in heat production is much less than that found in the comparison experiment with A. H. M.; the increments for carbon-dioxide production and oxygen consumption also vary considerably in the two experiments. From the results of these experiments it is evident that the ingestion of approximately 375 grams of beefsteak results in an increased metabolism which is essentially completed at the end of 6 hours, as the values obtained for the last 2-hour period of both 8-hour experiments indicate that the basal level for the metabolism had again been reached.

TABLE 201.—*A. W. W., May 25, 1907. Sitting.* (2-hour periods.)

Beefsteak:
Amount, 373 grams; nitrogen, 18.62 grams; total energy, 1,144 cals.
Fuel value: Total, 981 cals.; from protein, 49 p. ct.; from fat, 51 p. ct.
Basal values (March 15 and 21, 1907): CO_2, 50 grams; O_2, 41 grams; heat, 155 cals.

Time elapsed since subject finished eating.	Nitrogen in urine per 2 hours.	Carbon dioxide.		Oxygen.		Heat.[2]		Respiratory quotient.
		Total.	Increase.	Total.	Increase.	Total.	Increase.	
	grams.	*grams.*	*grams.*	*grams.*	*grams.*	*cals.*	*cals.*	
½ to 2½ hours	[3]0.92	57	7	51	10	171	16	0.81
2½ to 4½ hours	1.61	55	5	51	10	171	16	.79
4½ to 6½ hours	1.95	59	9	54	13	173	18	.80
6½ to 8½ hours	1.75	49	−1	40	−1	150	−5	.87
Total....	....	220	20	196	32	665	45	....

[1]Subject ate beefsteak in 23 minutes.
[2]Heat eliminated corrected for change in body-weight, but not for change in body-temperature.
[3]Sample included amount for about 1 hour preceding eating of beefsteak.

BOSTON CALORIMETER EXPERIMENTS.

Following the construction of the respiration calorimeters[1] in the Nutrition Laboratory, a series of five experiments subsequent to the ingestion of beefsteak was made with the chair calorimeter, beginning on December 4, 1908. The first two were 8-hour experiments, but the last three experiments continued for only 5 or 6 hours. The observations were made in 1-hour periods in all cases. The statistical data not included in the tables or discussion of these experiments are given in the following paragraphs; no additional data were available for L. E. E.:

J. R., 9h45m a. m. to 5h45m p. m., December 4, 1908. 66.2 kilograms.—Drank water at 10 a. m. (198 grams); urinated 7, 9h57m, 11h58m a. m., 2, 3h59m, and 5h55m p. m. Head ached after 2h30m p. m. Pulse rate, 62; these records sometimes difficult to obtain and at times pulse rate very low. No records could be obtained last half hour. Respiration rate, 17; but one record obtained after 4h45m p. m. Nitrogen in urine per hour 7 a. m. to 9h57m a. m., 0.48 gram.

F. M. M., 9h01m a. m. to 5h01m p. m., December 10, 1918. 59.8 kilograms.—In seventh period showed tendency to fall asleep; instructed to ring signal bell every five minutes. Urinated 7h05m, 9h01m, 11h01m a. m., 1h01m, 3h01m, and 5h01m p. m. Drank water at 9h01m a. m., 11h01m a. m., 2h01m p. m., and 4h01m p. m. (total amount, 998 grams). Pulse rate, 52. Nitrogen in urine per hour 7h05m a. m. to 9h01m a. m., 0.48 gram.

F. M. M., 8h55m a. m. to 2h55m p. m., December 23, 1908. 59.8 kilograms.—Did not eat all beefsteak provided, owing to pain in stomach; feared that a larger amount might increase pain and prevent experiment. Urinated and defecated at 7h30m a. m., also urinated at 11 a. m., 1 p. m., and 3 p. m.; drank water at 9 a. m., 11 a. m., and 1 p. m. (681 grams in all). Body-temperature: 36.75°, 36.95°, 36.79°, 36.69°, 36.66°, 36.72°, 36.85° C. Pulse rate, 56.

[1]Benedict and Carpenter, Carnegie Inst. Wash. Pub. No. 123, 1910.

F. M. M., 9h26m a. m. to 3h06m p. m., January 20, 1910. 61.5 kilograms.—Third period lengthened owing to unaccountable variations in the temperature conditions at end of hour. Nitrogen in urine per hour 6h45m a. m. to 10h30m a. m., 0.85 gram.

DISCUSSION OF EXPERIMENTS.

J. R., December 4, 1908.—The basal value for this experiment was determined on December 3. After the ingestion of 418 grams of beefsteak on December 4, having a nitrogen content of 15.30 grams, an increment in the carbon-dioxide production was noted in all of the eight periods, although the values had nearly reached the basal level in the last period (see table 202). Noticeable increments in the oxygen consumption were also found throughout the experiment; even in the eighth hour there was a consumption of 4 grams more than the basal requirement. The heat production was likewise increased in all of the periods. The maximum increments for carbon-dioxide production and oxygen consumption were noted in the third hour of the experiment, while that for heat production was found in the first period. The total increment, both in carbon-dioxide production and in oxygen consumption, was 31.5 grams; in heat production it was 104 calories. As the basal level had not been reached at the end of the experiment, the stimulus of the beefsteak was apparently still effective. The large excretion of nitrogen in the urine, with a total increment of 7.80 grams for the 8 periods, indicates a considerable katabolism of protein during the experiment.

TABLE 202.—*J. R., December 4, 1908. Sitting.* (1-hour periods.)

Beefsteak:
Amount, 418 grams; nitrogen, 15.30 grams; total energy, 737 cals.
Fuel value: Total, 603 cals.; from protein, 65 p. ct.; from fat, 35 p. ct.
Basal values (December 3, 1908): CO_2, 26.5 grams; O_2, 23.5 grams.; heat,[1] 74 cals. Nitrogen in urine, 0.38 gram per hour (December 4, 1908).

Time elapsed since subject finished eating.	Nitrogen in urine per hour.	Carbon dioxide.			Oxygen.			Heat.[1]			Respiratory quotient.
		Total.	Increase.		Total.	Increase.		Total.	Increase.		
			Total.	Per cent.		Total.	Per cent.		Total.	Per cent.	
	grams.	*grams.*	*grams.*		*grams.*	*grams.*		*cals.*	*cals.*		
1½ to 2½ hours	0.85	33.0	6.5	25	28.5	5.0	21	95	21	28	0.85
2½ to 3½ hours	.85	30.5	4.0	15	27.0	3.5	15	84	10	14	.81
3½ to 4½ hours	.96	33.5	7.0	26	32.5	9.0	38	93	19	26	.75
4½ to 5½ hours	.96	31.0	4.5	17	26.5	3.0	13	87	13	18	.85
5½ to 6½ hours	1.10	30.5	4.0	15	26.0	2.5	11	86	12	16	.85
6½ to 7½ hours	1.10	28.5	2.0	8	25.5	2.0	9	84	10	14	.82
7½ to 8½ hours	.99	28.5	2.0	8	26.0	2.5	11	83	9	12	.80
8½ to 9½ hours	.99	28.0	1.5	6	27.5	4.0	17	84	10	14	.74
Total ...	....	243.5	31.5	15	219.5	31.5	17	696	104	18	....

[1]Heat eliminated corrected for change in body-weight, but not for change in body-temperature.

F. M. M., December 10, 1908.—A somewhat smaller amount of beefsteak was taken by this subject than that taken by the subject of the preceding experiment, the amount in this case being 217 grams, with a nitrogen content of 9.97 grams. As in the experiment with J. R., the urine was collected every 2 hours. The results of the experiments are given in table 203, from which it is seen that the increase in carbon-dioxide production in each of the first three periods amounted to 3 grams or over; in the 5 hours following it was practically 1 gram above the basal value. Since a possible error of 1 or 1.5 grams in the basal value is permissible, one may conclude from the values for carbon-dioxide production alone that the basal value was reached at the end of the third hour. Irregular increments, which are difficult to explain, were found for oxygen consumption throughout the whole experiment. The maximum increase was 7 grams in the first hour and the lowest, 0.5 gram, in the fifth period. Somewhat large increments were noted in the sixth, seventh, and eighth hours which indicate that if the experimental technique were accurate, the basal level was not reached at the end of the experiment. A measurable increment in heat production occurred in the first 3 hours, but subsequently irregular values were found, with an increase of 5 calories in the sixth period, followed by a decrease of 6 calories in the seventh period, this variation possibly indicating a compensation. From the standpoint of direct calorimetry, the experiment can hardly be called successful. If we base our conclusion upon the values obtained for carbon-dioxide excretion and heat production, it is probable that the basal level was reached in approximately the fourth hour. The respiratory quotients indicate a leakage of air in the last three periods.

TABLE 203.—*F. M. M., December 10, 1908. Sitting.* (1-hour periods.)

Beefsteak:
Amount, 217 grams; nitrogen, 9.97 grams; total energy, 451 cals.
Fuel value: Total, 364 cals.; from protein, 70 p. ct.; from fat, 30 p. ct.
Basal values (December 9, 1908): CO_2, 25 grams; O_2, 21 grams; heat, 77 cals.

Time elapsed since subject finished eating.	Nitrogen in urine per hour.	Carbon dioxide.		Oxygen.		Heat.[1]		Respiratory quotient.
		Total.	Increase.	Total.	Increase.	Total.	Increase.	
	gram.	*grams.*	*grams.*	*grams.*	*grams.*	*cals.*	*cals.*	
1¼ to 2¼ hours	0.73	30.5	5.5	28.0	7.0	91	14	0.79
2¼ to 3¼ hours	.73	29.5	4.5	22.5	1.5	79	2	.94
3¼ to 4¼ hours	.79	28.0	3.0	26.5	5.5	85	8	.77
4¼ to 5¼ hours	.79	26.0	1.0	24.5	3.5	78	1	.77
5¼ to 6¼ hours	.67	25.5	0.5	21.5	0.5	75	−2	.85
6¼ to 7¼ hours	.67	26.5	1.5	26.0	5.0	82	5	.75
7¼ to 8¼ hours	.60	26.0	1.0	25.0	4.0	71	−6	.75
8¼ to 9¼ hours	.60	26.5	1.5	24.5	3.5	79	2	.78
Total....	....	218.5	18.5	198.5	30.5	640	24	....

[1]Heat eliminated corrected for change in body-weight, but not for change in body-temperature.

F. M. M., December 23, 1908.—In this second experiment with F. M. M. 208 grams of beefsteak, with a nitrogen content of 9.55 grams, were ingested, this being approximately the same as in the experiment on December 10. The observations continued for only 6 hours, the urine being collected in 2-hour periods as before. Increments in carbon-dioxide production were noted in the first three periods, also in oxygen consumption. (See table 204.) Irregular values were obtained for both factors thereafter. This irregularity was also shown in heat production, as increments were obtained for the first and third periods and a basal value in the second period. As the irregularity in values is very pronounced, one may regard it as probable that the total effect of the beefsteak was obtained in the first 3 or possibly 4 hours, as also in the experiment with this subject on December 10, 1908.

TABLE 204.—*F. M. M., December 23, 1908. Sitting.* (1-hour periods.)

Beefsteak:
Amount, 208 grams; nitrogen, 9.55 grams; total energy, 433 cals.
Fuel value: Total, 349 cals.; from protein, 70 p. ct.; from fat, 30 p. ct.
Basal values (December 9 to 29, 1908): CO_2, 25.5 grams; O_2, 22.5 grams; heat,[1] 75 cals.

Time elapsed since subject finished eating.	Nitrogen in urine per hour.	Carbon dioxide.		Oxygen.		Heat.[1]		Respiratory quotient.
		Total.	Increase.	Total.	Increase.	Total.	Increase.	
	gram.	*grams.*	*grams.*	*grams.*	*grams.*	*cals.*	*cals.*	
1 to 2 hours...	[2]0.57	30.0	4.5	24.5	2.0	80	5	0.88
2 to 3 hours...	[2].57	28.5	3.0	24.5	2.0	75	0	.84
3 to 4 hours...	.61	30.0	4.5	24.0	1.5	82	7	.91
4 to 5 hours...	.61	25.0	−0.5	21.0	−1.5	77	2	.86
5 to 6 hours...	.65	28.0	2.5	24.0	1.5	78	3	.84
6 to 7 hours...	.65	26.0	0.5	22.5	0.0	75	0	.83
Total....	....	167.5	14.5	140.5	5.5	467	17	....

[1]Heat eliminated corrected for change in body-weight, but not for change in body-temperature.
[2]Sample included amount for about 1½ hours preceding the first period.

F. M. M., January 20, 1910.—In the experiment recorded in table 205, only 132 grams of beefsteak were eaten, with a nitrogen content of 6.05 grams. Increments in carbon-dioxide production and oxygen consumption were noted in the first 2 hours; thereafter values below the basal value were observed. The heat production showed an increment in the first five of the six periods. The only conclusion which can be drawn from this experiment is that the effect of the ingestion of beefsteak probably continued for 2 hours. The basal values used in this experiment were the average of results obtained in four experiments made within a month of the experiment with beefsteak. These appeared to be the most suitable basal values available, but the irregularities in the increments, as well as the appearance of values lower than basal, serve to accentuate the difficulties of measuring slight increases when the basal value is uncertain.

TABLE 205.—*F. M. M., January 20, 1910. Sitting.* (1-hour periods.)

Beefsteak:
Amount, 132 grams; nitrogen, 6.05 grams; total energy, 274 cals.
Fuel value: Total, 221 cals.; from protein, 70 p. ct.; from fat, 30 p. ct.
Basal values (January 31 to February 19, 1910): CO_2, 26.5 grams; O_2, 23 grams; heat,[1] 80 cals.

Time elapsed since subject finished eating.	Nitrogen in urine per hour.	Carbon dioxide.		Oxygen.		Heat.[1]		Respiratory quotient.
		Total.	Increase.	Total.	Increase.	Total.	Increase.	
	gram.	*grams.*	*grams.*	*grams.*	*grams.*	*cals.*	*cals.*	
1¼ to 2¼ hours	[2]0.85	30.0	3.5	25.0	2.0	85	5	0.88
2¼ to 3¼ hours	....	29.0	2.5	25.0	2.0	84	4	.86
3¼ to 6 hours	....	24.0	−2.5	22.0	−1.0	83	3	.81
	....	24.0	−2.5	22.0	−1.0	83	3	.81
	....	24.0	−2.5	22.0	−1.0	83	3	.81
6 to 7 hours	....	25.5	−1.0	22.0	−1.0	74	−6	.85
Total....	....	[3]149.5	[3]−0.5	[3]129.5	[3]−1.0	[3]463	[3]10	....

[1]Heat eliminated corrected for change in body-weight, but not for change in body-temperature.
[2]Sample included amount for about 1¼ hours without food and for 1½ hours with food preceding this period.
[3]Total amounts for the actual duration of the experiment, *i. e.*, 5^h40^m.

L. E. E., January 17, 1910.—But 163 grams of beefsteak, with a nitrogen content of 7.20 grams, were eaten by the subject in this experiment; the values obtained thereafter are given in table 206. Considerable increments in the carbon-dioxide production, oxygen consumption, and heat production were found throughout the whole experiment. Unfortunately it is necessary to use for basal values the results obtained in three experiments several months later; the base-line used may therefore be somewhat too low. It is not impossible that somewhat smaller increments would have been obtained than appear here if the

TABLE 206.—*L. E. E., January 17, 1910. Sitting.* (1-hour periods.)

Beefsteak:
Amount, 163 grams; nitrogen, 7.20 grams; total energy, 308 cals.
Fuel value: Total, 245 cals.; from protein, 75 p. ct.; from fat, 25 p. ct.
Basal values (March 14 to May 11, 1910): CO_2, 25.5 grams; O_2, 21.5 grams; heat,[1] 76 cals.

Time elapsed since subject finished eating.	Carbon dioxide.		Oxygen.		Heat.[1]		Respiratory quotient.
	Total.	Increase.	Total.	Increase.	Total.	Increase.	
	grams.	*grams.*	*grams.*	*grams.*	*cals.*	*cals.*	
2½ to 3½ hours.....	28.5	3.0	24.0	2.5	89	13	0.86
3½ to 4½ hours.....	29.0	3.5	24.5	3.0	83	7	.85
4½ to 5½ hours.....	27.5	2.0	24.5	3.0	86	10	.82
5½ to 6½ hours.....	27.0	1.5	25.5	4.0	81	5	.78
6½ to 7½ hours.....	28.0	2.5	26.5	5.0	88	12	.76
Total.....	140.0	12.5	125.0	17.5	427	47	....

[1]Heat eliminated corrected for change in body-weight, but not for change in body-temperature

basal value had been determined on the experimental day, but since the experiment is made on much the same plan as those in other laboratories, it is included in this discussion. Disregarding the high values obtained in the last period, the only conclusion which can be drawn from these imperfect data is that there was a positive increment in the metabolism for at least 3 hours as a result of ingestion of this amount of beefsteak.

BEEFSTEAK AND SMALL AMOUNTS OF OTHER FOOD MATERIALS.

In addition to the calorimeter experiments in which beefsteak alone was eaten, a number of experiments were made in which the diet included small amounts of bread or potato chips. The fact that these small quantities of other food materials were taken will not, however, materially interfere with the use of the results for comparison with those obtained when only beefsteak was given. Emphasis has already been laid upon the fact that the beefsteak was by no means a pure protein material and contained a relatively large amount of fat, approximately 30 to 40 per cent of the fuel value in most of the experiments previously discussed being derived from this substance. The chair calorimeter in Boston was used in all of the experiments but one, the exception being an experiment with beefsteak and potato chips in which the bed calorimeter was used.

BEEFSTEAK AND BREAD.

Three calorimeter experiments with beefsteak and bread were made, all with one subject. Approximately 200 to 250 grams of beefsteak were taken with 24 to 50 grams of bread. The statistical data regarding these experiments, not included in the tables or in the discussion, are given in the following paragraphs:

F. M. M., 10^{h}14^{m} a. m. to 3^{h}14^{m} p. m., January 11, 1910. 60.4 kilograms.—Moved about considerably in first period and at end of period was swinging back and forth in chair. Urinated 7^{h}30^{m} a. m., 10^{h}20^{m} a. m., 3^{h}25^{m} p. m. Body-temperature: 36.76°, 36.71°, 36.85°, 36.86°, 36.83°, 36.99° C.

F. M. M., 9^{h}28^{m} a. m. to 2^{h}28^{m} p. m., January 12, 1910.—Nitrogen in urine per hour 7^{h}30^{m} a. m. to 12^{h}57^{m} p. m., 0.86 gram.

F. M. M., 9^{h}24^{m} a. m. to 2^{h}24^{m} p. m., January 14, 1910.—Subject in nervous and depressed condition before entering apparatus from causes having no connection with experiment. Nitrogen in urine per hour 7^{h}40^{m} a. m. to 1^{h}36^{m} p. m., 0.74 gram; 1^{h}36^{m} p. m. to 2^{h}35^{m} p. m., 0.78 gram.

Discussion of Experiments.

F. M. M., January 11, 1910.—The results of the experiment on this date are recorded in table 207. The food taken consisted of 246 grams of beefsteak and 50 grams of bread, with a nitrogen content of 10.70 grams. But one collection of urine was made for the experimental

period, the nitrogen excretion being 0.52 gram per hour. The increment in carbon-dioxide production in the first 4 hours of this 5-hour experiment was considerable. Both the oxygen consumption and heat production were likewise above the basal requirements. A total increment of 13.5 grams was found in both carbon-dioxide production and oxygen consumption, and in heat production of 44 calories. While in all probability the addition to the diet of the small amount of carbohydrate in bread affected slightly the carbon-dioxide production, nevertheless the ingestion of the beefsteak was undoubtedly the main cause of the increment noted with all three factors.

TABLE 207.—*F. M. M., January 11, 1910. Sitting.* (1-hour periods.)

Beefsteak and bread:

Amounts, 246 grams beefsteak, 50 grams bread; nitrogen, 10.79 grams; total energy, 574 cals.
Fuel value: Total, 480 cals.; from protein, 58 p. ct.; from fat, 20 p. ct.; from carbohydrates, 22 p. ct.
Nitrogen in urine, 0.52 gram per hour.[1]

Basal values (January 31 to February 19, 1910): CO_2, 26.5 grams; O_2, 23 grams; heat,[2] 80 cals.

Time elapsed since subject finished eating.	Carbon dioxide.		Oxygen.		Heat.		Respiratory quotient.
	Total.	Increase.	Total.	Increase.	Total.	Increase.	
	grams.	*grams.*	*grams.*	*grams.*	*cals.*	*cals.*	
2¼ to 3¼ hours	30.5	4.0	27.5	4.5	89	9	0.81
3¼ to 4¼ hours	30.0	3.5	24.5	1.5	93	13	.89
4¼ to 5¼ hours	29.0	2.5	25.0	2.0	89	9	.84
5¼ to 6¼ hours	29.0	2.5	27.5	4.5	83	3	.77
6¼ to 7¼ hours	27.5	1.0	24.0	1.0	90	10	.84
Total...	146.0	13.5	128.5	13.5	444	44	....

[1]Nitrogen in an earlier sample for one-half hour before food and 2¼ hours after food was 1.11 grams per hour.

[2]Heat eliminated corrected for change in body-weight, but not for change in body-temperature.

F. M. M., January 12, 1910.—The amounts of both beefsteak and bread eaten before this experiment were somewhat smaller than on the previous day, being 199 grams and 38 grams, respectively, with a nitrogen content of 8.91 grams. There was a marked increase in the carbon-dioxide production in the first two periods, which was possibly due in part to the carbohydrate material. The significant increase in the oxygen consumption and heat production also occurred in the first two periods. It would appear, therefore, from this experiment that the influence of the beefsteak and bread upon the metabolism was practically at an end at the conclusion of the second 1-hour period. The nitrogen excretion was measurably greater than in the first experiment of the series, indicating a larger katabolism of protein. The results of the experiment are given in table 208.

F. M. M., January 14, 1910.—With 201 grams of beefsteak only 24 grams of bread were eaten in the experiment on this date, correspond-

TABLE 208.—*F. M. M., January 12, 1910. Sitting.* (1-hour periods.)

Beefsteak and bread:

Amounts, 199 grams beefsteak, 38 grams bread; nitrogen, 8.91 grams; total energy, 493 cals.
Fuel value: Total, 415 cals.; from protein, 55 p. ct.; from fat, 25 p. ct.; from carbohydrates, 20 p. ct.
Nitrogen in urine, 0.86 gram per hour.[1]

Basal values (January 31 to February 19, 1910): CO_2, 26.5 grams; O_2, 23 grams; heat,[2] 80 cals.

Time elapsed since subject finished eating.	Carbon dioxide.		Oxygen.		Heat.[2]		Respiratory quotient.
	Total.	Increase.	Total.	Increase.	Total.	Increase.	
	grams.	*grams.*	*grams.*	*grams.*	*cals.*	*cals.*	
1 to 2 hours...	33.5	7.0	27.5	4.5	88	8	0.88
2 to 3 hours...	30.5	4.0	28.5	5.5	96	16	.78
3 to 4 hours...	27.0	0.5	20.5	−2.5	80	0	.96
4 to 5 hours...	27.5	1.0	25.0	2.0	86	6	.80
5 to 6 hours...	27.0	0.5	24.0	1.0	82	2	.81
Total...	145.5	13.0	125.5	10.5	432	32	....

[1]Amount does not cover the duration of the experiment by 1½ hours; sample included amount for about 2 hours preceding the first period.

[2]Heat eliminated corrected for change in body-weight, but not for change in body-temperature.

ing to about 13 grams of carbohydrate. This amount probably had but little, if any, effect upon the carbon-dioxide production. The food contained 9.55 grams of nitrogen. The results of the experiment are given in table 209. Apparently the ingestion of the beefsteak and bread produced a marked effect upon the metabolism of the subject, as the increase continued throughout the 5-hour experiment, although the nitrogen excretion per hour was not so great as in the experiment on January 12. (See table 208.) It is unfortunate that a basal value for this experiment could not have been determined on the same day,

TABLE 209.—*F. M. M., January 14, 1910. Sitting.* (1-hour periods.)

Beefsteak and bread:

Amounts, 201 grams beefsteak, 24 grams bread; nitrogen, 9.55 grams; total energy, 483 cals.
Fuel value: Total, 399 cals.; from protein, 61 p. ct.; from fat, 26 p. ct.; from carbohydrates, 13 p. ct.

Basal values (January 31 to February 19, 1910): CO_2, 26.5 grams; O_2, 23 grams; heat,[1] 80 cals.

Time elapsed since subject finished eating.	Nitrogen in urine per hour.	Carbon dioxide.		Oxygen.		Heat.[1]		Respiratory quotient.
		Total.	Increase.	Total.	Increase.	Total.	Increase.	
	gram.	*grams.*	*grams.*	*grams.*	*grams.*	*cals.*	*cals.*	
1¼ to 2¼ hours	0.74	32.5	6.0	25.0	2.0	92	12	0.94
2¼ to 3¼ hours	.74	32.5	6.0	29.0	6.0	93	13	.82
3¼ to 4¼ hours	.74	30.5	4.0	26.5	3.5	92	12	.84
4¼ to 5¼ hours	.74	29.0	2.5	24.0	1.0	85	5	.88
5¼ to 6¼ hours	.78	29.5	3.0	29.5	6.5	84	4	.73
Total....	...	154.0	21.5	134.0	19.0	446	46	....

[1]Heat eliminated corrected for change in body-weight, but not for change in body-temperature.

for the total increments computed from the basal values and the values measured after the ingestion of the food are much larger than in the two preceding experiments with the same subject and with essentially the same protein intake. The chief value of the results of this experiment lies in the fact that they show the highest effect to be found in the first few hours after the ingestion of food.

BEEFSTEAK AND POTATO CHIPS.

As it was somewhat difficult for the subjects to eat beefsteak alone, approximately 20 grams of potato chips were taken in a few of the Boston calorimeter experiments. The potato chips contained a considerable proportion of fat and about the same amount of carbohydrate.[1] The carbohydrate thus added to the diet was not sufficient to affect the measurements appreciably and, in view of the relatively large amount of fat in the beefsteak, it was assumed that the additional fat in the potato chips would play but a small part in the total metabolism. The five experiments in this series were made between January 17 and May 11, 1911, the amount of beefsteak ranging from 193 to 272 grams. These experiments continued for 3 hours after the food was ingested. Thus the total time for the preceding basal experiment and the food experiment was about 8 hours, which was as long as it was practicable for the subjects to remain quiet. In all cases the measurements were made in periods of 45 minutes. It was subsequently decided that observations of this length with the calorimeter did not give results with a sufficient degree of accuracy and their use was discontinued in later experimenting. Except in the experiment with J. J. C. on May 11, 1911, the basal values for this series of observations were determined on the same day as the metabolism subsequent to the ingestion of the beefsteak and potato chips. Truly comparable values were thus obtained. Statistical data not included in the tables or in the discussion of the experiments are here given:

J. J. C., 9^{h}24^m a. m. to 3^{h}37^m p. m., January 17, 1911. 64.9 kilograms. 3 basal periods.—Low-carbohydrate supper preceding day. Basal periods ended 11^{h}42^m a. m.; food periods began 12^{h}37^m p. m. Went to sleep at beginning of first basal period, but was wakened 20 minutes after period had begun; very quiet all of this period, reading when awake. Quiet for most part in second basal period, dozing slightly once. Very quiet in last basal period, also in first, second, and third food periods, and slept part of time in third food period. More wide-awake in last food period than previously and very quiet, especially at end. Urinated 7 a. m., 11^{h}04^m a. m., and 3^{h}50^m p. m.; went through motions of urinating each period, usually near beginning of period. Basal periods: pulse rate, 62; respiration rate, 17. Food periods: pulse rate, 64; respiration rate, 17.

J. J. C., 12^{h}15^m p. m. to 6^{h}15^m p. m., May 11, 1911. 64.6 kilograms.—Very quiet throughout experiment, sleeping greater part of time. Moved consider-

[1] See p. 258 and table 50.

ably near beginning of both second and sixth periods, answering telephone in latter period and adjusting stethoscope. Urinated 8 a. m., 10^h50^m a. m., and 6^h23^m p. m. Body-temperature: 37.12°, 37.11°, 37.00°, 36.94°, 36.88°, 36.71°, 36.59°, 36.43°, 36.47° C. Pulse rate, 59.

C. H. H., 8^h58^m a. m. to 2^h18^m p. m., January 18, 1911. 54.8 kilograms. 2 basal periods.—Basal periods ended at 10^h28^m a. m.; food periods began at 11^h18^m a. m. Urinated and defecated at 6^h30^m a. m. and urinated at 2^h47^m p. m. Quiet throughout experiment. Basal periods: pulse rate, 68; respiration rate, 16. Food periods: pulse rate, 74; respiration rate, 18.

V. G., 8^h55^m a. m. to 2^h45^m p. m., January 21, 1911. 55.3 kilograms. 2 basal periods.—Low carbohydrate supper previous day. Basal periods ended at 10^h25^m a. m.; food periods began at 11^h43^m a. m. Drank 154 c.c. water with food. Urinated 7^h48^m a. m., 10^h35^m a. m., 3 p. m.; went through motions of urinating near beginning of each period. Basal periods: pulse rate, 67; respiration rate, 21. Food periods: pulse rate, 66; respiration rate, 21.

A. G. E., 8^h47^m a. m. to 2^h52^m p. m., January 23, 1911. 56.4 kilograms. 2 basal periods.—Basal periods ended 10^h17^m a. m.; food periods began 11^h52^m a. m. Drank 125 c.c. water with food. Very quiet throughout whole experiment; urinated 7 a. m., 10^h28^m a. m., 3 p. m. Basal periods: pulse rate, 70; respiration rate, 15. Food periods: pulse rate, 72; respiration rate, 15.

Discussion of Experiments.

J. J. C., January 17, 1911.—The results of the experiment are given in table 210, from which it is seen that the increment in metabolism continued throughout the four periods. The inference from the values obtained would be that the effect of the food was still persisting at the end of the experiment. This appears the more probable, for we have here no uncertain basal value, as the post-absorptive metabolism values were also determined on this day. It is clear, therefore, that with this

Table 210.—*J. J. C., January 17, 1911. Sitting.* (45-minute periods.)

Beefsteak and potato chips:

Amounts, 193 grams beefsteak, 20 grams potato chips; nitrogen, 8.99 grams; total energy, 504 cals.

Fuel value: Total, 425 cals.; from protein, 54 p. ct.; from fat, 39 p. ct.; from carbohydrates, 7 p. ct.

Nitrogen in urine, 0.44 gram per 45 minutes.[1]

Basal values (January 17, 1911): CO_2, 19.5 grams; O_2, 18 grams; heat (computed), 60 cals.; respiratory quotient, 0.78. Nitrogen in urine, 0.32 gram per 45 minutes.

Time elapsed since subject finished eating.	Carbon dioxide.		Oxygen.		Heat (computed).		Respiratory quotient.
	Total.	Increase.	Total.	Increase.	Total.	Increase.	
	grams.	*grams.*	*grams.*	*grams.*	*cals.*	*cals.*	
½ to 1½ hours	22.0	2.5	19.5	1.5	66	6	0.82
1½ to 2 hours	21.5	2.0	19.5	1.5	65	5	.81
2 to 2¾ hours	21.5	2.0	21.5	3.5	70	10	.74
2¾ to 3½ hours	22.5	3.0	20.0	2.0	67	7	.83
Total...	87.5	9.5	80.5	8.5	268	28	....

[1]Sample included amount for about 1 hour preceding eating of food.

subject the eating of 193 grams of beefsteak with a nitrogen content of 8.99 grams and 20 grams of potato chips, resulted in an increased metabolism which persisted at a noticeable level for the 3 hours of the experiment.

J. J. C., May 11, 1911.—This is one of the few experiments in this research in which the bed calorimeter was used instead of the chair calorimeter. In the bed calorimeter there is usually a somewhat greater degree of muscular repose, as the subject is lying down instead of sitting up in a chair. The post-absorptive metabolism for J. J. C. was not determined on the same day with the bed calorimeter; it was therefore necessary to utilize post-absorptive values obtained with the apparatus in experiments made between October 27 and November 15, 1910, approximately 6 months prior to the experiment with beefsteak and potato chips. In the experiment with this subject on January 17, it appeared that the full effect of the food was not determined during the period of the observations; the experiment on May 11 was therefore continued for eight 45-minute periods instead of for four periods, as in the other experiments of the series. The results of the experiment are given in table 211.

TABLE 211.—*J. J. C., May 11, 1911. Lying.* (45-minute periods.)

Beefsteak and potato chips:

Amounts, 270 grams beefsteak, 41 grams potato chips; nitrogen, 12.67 grams; total energy, 787 cals.

Fuel value: Total, 676 cals.; from protein, 48 p. ct.; from fat, 41 p. ct.; from carbohydrates, 11 p. ct.

Nitrogen in urine, 0.51 gram per 45 minutes.[1]

Basal values (October 27 to November 15, 1910): CO_2, 17 grams; O_2, 14 grams; heat,[2] 49 cals.

Time elapsed since subject finished eating.	Carbon dioxide.		Oxygen.		Heat.[2]		Respiratory quotient.
	Total.	Increase.	Total.	Increase.	Total.	Increase.	
	grams.	*grams.*	*grams.*	*grams.*	*cals.*	*cals.*	
4 to 4¾ hours	21.5	4.5	17.0	3.0	56	7	0.93
4¾ to 5½ hours	19.5	2.5	18.0	4.0	61	12	.78
5½ to 6¼ hours	19.0	2.0	16.0	2.0	55	6	.87
6¼ to 7 hours	18.5	1.5	16.0	2.0	61	12	.85
7 to 7¾ hours	17.0	0.0	15.5	1.5	57	8	.80
7¾ to 8½ hours	17.5	0.5	16.5	2.5	56	7	.77
8½ to 9¼ hours	17.0	0.0	14.0	0.0	43	−6	.89
9¼ to 10 hours	17.0	0.0	16.5	2.5	46	−3	.75
Total...	147.0	11.0	129.5	17.5	435	43	....

[1]Nitrogen in an earlier sample for 2¾ hours following the eating of the food was 0.50 gram per 45 minutes.

[2]Heat eliminated corrected for change in body-weight, but not for change in body-temperature.

Following the ingestion of 270 grams of beefsteak, with a nitrogen content of 12.67 grams, and 41 grams of potato chips, the increment in carbon-dioxide production continued for only four periods. The

increment in oxygen consumption was irregular after the first four periods and reached a basal value in the seventh period, but again increased in the last period. The increment in heat production was found in all of the periods but the last two, when values slightly below the basal were obtained.

C. H. H., January 18, 1911.—The results of the experiment are given in table 212. As a result of the ingestion of 213 grams of beefsteak with a nitrogen content of 9.91 grams, and 20 grams of potato chips, the carbon-dioxide production showed a slight increment in all of the periods; the only notable increase was that in the third period. As the basal value was obtained on the same day, the slight gains can not be attributed to inaccuracy of the base-line. Both oxygen consumption and heat production showed a similar general picture of small increments, with the maximum in the third period. As the basal values had not been reached at the end of the experiment, it is probable that the influence of the ingestion of food was still in effect.

TABLE 212.—*C. H. H., January 18, 1911. Sitting.* (45-minute periods.)

Beefsteak and potato chips:

Amounts, 213 grams beefsteak, 20 grams potato chips; nitrogen, 9.91 grams; total energy, 547 cals.

Fuel value: Total, 460 cals.; from protein, 55 p. ct.; from fat, 36 p. ct.; from carbohydrates, 9 p. ct.

Nitrogen in urine, 0.25 gram per 45 minutes.[1]

Basal values (January 18, 1911): CO_2, 16.5 grams; O_2, 15 grams; heat,[2] 45 cals.; respiratory quotient, 0.81.

Time elapsed since subject finished eating.	Carbon dioxide.		Oxygen.		Heat.[2]		Respiratory quotient.
	Total.	Increase.	Total.	Increase.	Total.	Increase.	
	grams.	*grams.*	*grams.*	*grams.*	*cals.*	*cals.*	
½ to 1¼ hours	17.0	0.5	16.0	1.0	48	3	0.77
1¼ to 2 hours	17.5	1.0	15.5	0.5	49	4	.81
2 to 2¾ hours	19.0	2.5	17.5	2.5	50	5	.78
2¾ to 3½ hours	17.5	1.0	16.0	1.0	48	3	.78
Total...	71.0	5.0	65.0	5.0	195	15	....

[1]Sample included amount for 4 hours without food preceding the eating of beefsteak and potato chips.

[2]Heat eliminated corrected for change in body-weight, but not for change in body-temperature.

V. G., January 21, 1911.—The amount of food taken by this subject was 215 grams of beefsteak, with a nitrogen content of 10 grams, and 20 grams of potato chips. The data given in table 213 show increments in carbon-dioxide production for the first three periods, and for oxygen consumption in the first two periods, with a basal value for the latter in the third period and an increase above basal in the fourth period. An increment in heat production was obtained in all of the periods, but that for the third period was slight. If the values for oxy-

gen consumption and heat production in the third period are correct, the metabolism had returned to the basal level in that period and the figures obtained for the fourth period were therefore abnormal and due to some extraneous factor. On the other hand, an examination of the respiratory quotients shows an abnormally high value of 0.89 in the third period, which suggests an error in the measurement of oxygen consumption with a possible compensation in the fourth period. An

TABLE 213.—*V. G., January 21, 1911. Sitting.* (45-minute periods.)

Beefsteak and potato chips:

Amounts, 215 grams beefsteak, 20 grams potato chips; nitrogen, 10 grams; total energy, 551 cals.

Fuel value: Total, 463 cals.; from protein, 55 p. ct.; from fat, 36 p. ct.; from carbohydrates, 9 p. ct.

Nitrogen in urine, 0.32 gram per 45 minutes.

Basal values: CO_2, 22 grams (January 21, 1911); O_2, 19 grams (January 2 and 21, 1911); heat (computed), 64 cals. (January 21, 1911). Nitrogen in urine, 0.20 gram per 45 minutes. (January 21, 1911).

Time elapsed since subject finished eating.	Carbon dioxide.		Oxygen.		Heat (computed).		Respiratory quotient.
	Total.	Increase.	Total.	Increase.	Total.	Increase.	
	grams.	*grams.*	*grams.*	*grams.*	*cals.*	*cals.*	
1 to 1¾ hours	22.5	0.5	20.5	1.5	68	4	0.79
1¾ to 2½ hours	23.5	1.5	23.0	4.0	75	11	.76
2½ to 3¼ hours	23.0	1.0	19.0	0.0	65	1	.89
3¼ to 4 hours	22.0	0.0	21.0	2.0	69	5	.77
Total...	91.0	3.0	83.5	7.5	277	21	....

TABLE 214.—*A. G. E., January 23, 1911. Sitting.* (45-minute periods.)

Beefsteak and potato chips:

Amounts, 272 grams beefsteak, 20 grams potato chips; nitrogen, 12.63 grams; total energy, 677 cals.

Fuel value: Total, 566 cals.; from protein, 57 p. ct.; from fat, 37 p. ct.; from carbohydrates, 6 p. ct.

Nitrogen in urine, 0.42 gram per 45 minutes.

Basal values (January 23, 1911): CO_2, 18 grams; O_2, 16 grams; heat,[1] 53 cals.; respiratory quotient, 0.82. Nitrogen in urine, 0.21 gram per 45 minutes.

Time elapsed since subject finished eating.[2]	Carbon dioxide.		Oxygen.		Heat.[1]		Respiratory quotient.
	Total.	Increase.	Total.	Increase.	Total.	Increase.	
	grams.	*grams.*	*grams.*	*grams.*	*cals.*	*cals.*	
¾ to 1½ hours	19.5	1.5	18.5	2.5	55	2	0.77
1½ to 2¼ hours	20.5	2.5	17.5	1.5	56	3	.84
2¼ to 3 hours	21.5	3.5	20.0	4.0	58	5	.78
3 to 3¾ hours	20.5	2.5	17.5	1.5	55	2	.86
Total...	82.0	10.0	73.5	9.5	224	12	....

[1] Heat eliminated corrected for change in body-weight, but not for change in body-temperature.

[2] Subject ate food in 28 minutes.

examination of the protocols of the experiment indicates that there was somewhat more repose when the basal values were obtained than during the measurement after the food was taken. The increments here noted would therefore be larger than would be expected if the degree of repose were the same in both experiments.

A. G. E., January 23, 1911.—After the ingestion of 272 grams of beefsteak with a nitrogen content of 12.63 grams, and 20 grams of potato chips, measurable increases were obtained for all of the factors of metabolism. (See table 214.) Although there is a lessening increment in the last period, the indications are that the stimulus to the metabolism had not ceased at the end of the experiment. The maximum values in all cases occur in the third period.

RESPIRATION EXPERIMENTS WITH BEEFSTEAK.

The series of respiration experiments with beefsteak included 14 experiments with 10 subjects made between November 3, 1910, and December 12, 1914. The routine in these experiments was not unlike that followed in similar experiments in this laboratory, the basal value being determined on the same day prior to the ingestion of food. After the food was eaten, measurements of the metabolism were usually begun immediately and continued at intervals in periods of approximately 15 minutes for a varying length of time. In one instance, the experiment with H. L. H., on July 1, 1911, the observations continued for 12 hours after the food was given, but in the majority of cases they ended inside of 3 to 6 hours. Throughout the whole experiment the subject lay quietly upon a couch and every effort was made to maintain constant muscular repose. The urine was usually obtained for both the basal and food periods. All available data regarding nitrogen excretion in these experiments are given in table 216. In most of the experiments the diet consisted of beefsteak alone, but in two instances small amounts of other food materials were added. It was assumed that these small amounts had practically no influence upon the metabolism.

The pronounced effect upon metabolism occasioned by the ingestion of even moderate amounts of a protein food material has been so clearly shown, not only in all of the experiments cited in the literature but likewise in our calorimeter experiments with beefsteak, that the results of these respiration experiments may be treated differently from those of the carbohydrate respiration experiments. The average respiratory quotient of normal man in the post-absorptive condition is not far from 0.83. Since this is approximately the respiratory quotient of protein katabolism, the respiratory quotients in our experiments with a protein diet do not have the special interest that they have in the carbohydrate experiments. Consequently it seems unnecessary to publish the de-

tails of these experiments, as our main interest lies in the influence of the ingestion of protein upon the heat production as computed from the values for oxygen consumption and carbon-dioxide production. We shall therefore confine our discussion chiefly to the changes in the energy output as the observations continued. The results of the respiration experiments with beefsteak have been summarized on this basis in table 215, which gives the amount of steak eaten, the basal heat production expressed in calories per minute, and the heat production in calories per minute for successive periods. The data are arranged according to the amount of beefsteak eaten, the largest amount being 362 grams and the smallest 150 grams. The data for the nitrogen excreted, so far as available, are given in table 216.

TABLE 215.—*Heat produced (computed) in respiration experiments with beefsteak.*
(Values per minute.)

Subject and date.	Amt. of beefsteak eaten.	Nitrogen in food.	Basal value.	After the ingestion of beefsteak.											Increase during period of observation.[1]	
				0 to 20 mins.	20 to 40 mins.	40 to 60 mins.	1 to 1½ hours.	1½ to 2 hours.	2 to 2½ hours.	2½ to 3 hours.	3 to 4 hours.	4 to 5 hours.	5 to 6 hours.	6 to 7 hours.	Total.	Per cent.
	gm.	*gm.*	*cal.*	*cal.*	*cal.*	*cal.*	*cal.*	*cal.*	*cal.*	*cal.*	*cal.*	*cal.*	*cal.*	*cal.*	*cal.*	
J. J. C....Apr. 25, 1911	362[2]	17.73	1.11	....	....	1.25	1.30	....	1.41	1.47	1.49	1.37	1.34	.....	81	23
H. L. H...May 20, 1914	317	14.56	1.14	....	....	1.28	1.29	1.29	....	....	....	....	....	.....	13	10
July 1, 1911	249	11.44	1.11	....	1.17	1.18	....	1.28	....	1.34	1.38	1.44	1.28	1.30[3]	138	18
H. G. E..Dec. 12, 1914	200	9.18	1.24	....	1.38	....	....	1.38	....	1.45	....	....	....	.....	25	12
J. F. M...Apr. 23, 1914	198	9.09	1.24	1.45	....	1.34	1.32	1.41	1.42	....	....	....	....	.....	19	11
J. K. M..Nov. 26, 1912	196	9.01	1.08	1.18	1.14	1.17	1.21	1.23	1.29	1.33	....	....	....	.....	28	14
D. M.....Oct. 28, 1911	182	8.35	1.09	....	1.26	....	1.34	1.35	1.47	1.58	....	1.30	1.26	.....	86	25
Dr. S.....June 30, 1911	177	8.13	0.93	....	1.05	....	1.08	....	1.11	1.13	1.13	1.05	1.03	1.00	56	15
A. J. O...Nov. 17, 1914	173	7.95	1.25	....	1.30	1.31	1.33	1.43	1.40	1.40	....	....	....	.....	17	8
H. H. A..Dec. 27, 1911	169[4]	8.59	1.10	....	....	....	....	....	....	....	....	1.35	1.36	.....	..	..
J. J. C....Nov. 3, 1910	150	7.74	1.10	....	1.16	....	1.24	1.32	1.37	1.40	1.34	1.37	....	.....	51	19
Nov. 8, 1910	150	6.92	1.12	1.10	....	1.14	....	1.15	1.26	....	1.34	....	....	.....	13	6
V. G.....Nov. 4, 1910	150	8.00	1.17	....	1.26	....	1.35	....	1.38	1.37	....	....	....	.....	24	13
Nov. 7, 1910	150	7.07	1.11	....	1.19	....	1.21	....	1.30	....	1.28	1.33	....	.....	38	13

[1]Time from the moment subject finished eating to the end of the last experimental period; see pp. 151 and 152 for method of obtaining total increase.

[2]Also 15 grams potato chips. Nitrogen in food includes the nitrogen in both beefsteak and potato chips.

[3]Additional values were obtained for 7 to 8, 8 to 9, 9 to 10, 10 to 11, 11 to 12 hours as follows: 1.39, 1.32, 1.29, 1.21, and 1.31 cals.

[4]Also 15 grams butter and 200 grams beef tea. Nitrogen in food includes nitrogen for all of the food eaten.

In computing the calories per minute the respiratory quotients as determined were used and not the non-protein respiratory quotients. A calculation of a few of these experiments showed practically no important changes due to a use of the non-protein quotient;[1] accordingly we may disregard the calculation and employment of the non-protein respiratory quotient and consider that the calorie output recorded in table 215 represents the heat production.

[1]See p. 203 for comparison made in typical experiments with levulose; similar comparisons made in experiments with beefsteak showed like small differences in the heat production.

TABLE 216.—*Nitrogen excreted in urine in respiration experiments with beefsteak.*

Subject and date.	Condition.	Period.	Finished eating.	Nitrogen per hour.
				grams.
J. J. C...Apr. 25, 1911..	Without food..	7^h41^ma.m. to 10^h15^ma.m.	.....	0.33
	With food....	10 15 a.m. to 4^h30^mp.m.	10^h31^ma.m.	.64
H. L. H..July 1, 1911..	Without food..	7 10 a.m. to 10 55 a.m.	.....	.58
	With food....	10 55 a.m. to 4 55 p.m.	11 15 a.m.	.86
	Do.	4 55 p.m. to 11 05 p.m.	.....	.69
H. G. E..Dec. 12, 1914..	Without food..	7 15 a.m. to 10 00 a.m.	.....	.32
	With food....	10 00 a.m. to 11 30 a.m.	10 15 a.m.	.49
	Do.	11 30 a.m. to 1 15 p.m.	.....	.56
J. K. M..Nov. 26, 1912..	.....	6 20 a.m. to 12 55 p.m.	11 10 a.m.	.51
D. M....Oct. 28, 1911..	Without food..	6 40 a.m. to 9 20 a.m.	.....	.58
	Do.	9 20 a.m. to 11 50 a.m.	.....	.52
	With food....	11 50 a.m. to 8 05 p.m.	2 48 p.m.	.67
Dr. S....June 30, 1911..	Without food..	7 15 a.m. to 10 40 a.m.	.....	.33
	With food....	10 40 a.m. to 1 30 p.m.	11 15 a.m.	.45
	Do.	1 30 p.m. to 5 03 p.m.	.....	.62
A. J. O...Nov. 17, 1914..	Without food..	7 50 a.m. to 9 55 a.m.	.....	.69
	With food....	9 55 a.m. to 11 20 a.m.	9 53 a.m.	.94
	Do.	11 20 a.m. to 12 45 p.m.	.....	1.08
J. J. C...Nov. 3, 1910..	Without food..	8 00 a.m. to 1 30 p.m.	.....	.37
	With food....	1 30 p.m. to 6 00 p.m.	1 40 p.m.	.57
Nov. 8, 1910..	Without food..	7 10 a.m. to 2 05 p.m.	.....	.32
	With food....	2 05 p.m. to 5 45 p.m.	2 28 p.m.	.38
V. G.....Nov. 4, 1910..	Without food..	7 42 a.m. to 2 55 p.m.	.....	.32
	With food....	2 55 p.m. to 6 05 p.m.	3 20 p.m.	.39
Nov. 7, 1910..	Without food..	7 30 a.m. to 11 18 a.m.	.....	.27
	Do.	11 18 a.m. to 1 05 p.m.	.....	.20
	With food....	1 05 p.m. to 5 40 p.m.	1 05 p.m.	.30

The pronounced increase over the basal metabolism is instantly noted in practically all experiments. As might be expected, the higher values are usually obtained with the larger amounts of steak. For instance, in the experiment with J. J. C. on April 25, 1911, when 362 grams of beefsteak were eaten, the basal value of 1.11 calories was increased to 1.49 calories between 3 and 4 hours after the food. As a matter of fact, the highest absolute increment was noted with only 182 grams of beefsteak, this being in the experiment with D. M. on October 28, 1911, when the basal value of 1.09 calories was increased in 3 hours to 1.58 calories, or approximately 45 per cent. Of special significance is the fact that the basal value was not reached in any of these experiments, even when the observations were continued for 12 hours.

It should again be pointed out that these results are open to the objection that, unlike Gigon's admirably planned experiments, the food material used was not a pure protein, but that there was a certain admixture of fat, even though all visible fat was removed. The data obtained in these respiration experiments show clearly, however, that the ingestion of beefsteak in amounts varying from 150 to 362 grams results in a sustained increase in metabolism which is for the most part

greater than that noted either with carbohydrate food materials or with fats. This effect in practically all instances continues over a much longer time than with either of the other nutrients, thus putting this protein food material in a distinctly special class so far as the influence upon the metabolism is concerned.

PROLONGED EFFECT OF PROTEIN.

Two respiration experiments were carried out in July, 1911, to study the metabolism several hours after the ingestion of beefsteak. In both instances the steak was eaten at midnight and the subsequent experiments began at approximately 8^h30^m a. m.

In the experiment with H. F. T., July 14, 1911, the subject ate 206 grams of beefsteak, with a nitrogen content of 9.46 grams; the first observation was made at 8^h36^m a. m. The heat production for this period, as shown by table 217, was 0.92 calorie per minute. The two succeeding periods did not show materially different results. If we compare the heat production in this experiment with the basal value of 0.92 calorie per minute found for this subject on July 10, 1911, it is clear that the effect of 206 grams of beefsteak had entirely passed at the end of $8\frac{1}{2}$ hours. The nitrogen excretion for approximately 11 hours after the ingestion of the food was as follows: Between 11^h45^m p. m., July 13, and 7 a. m., July 14, 0.80 gram per hour; between 7 a. m. and 10^h40^m a. m., July 14, 0.69 gram per hour.

TABLE 217.—*H. F. T., July 14, 1911. Lying.* (Values per minute.)

Beefsteak:
Amount, 206 grams; nitrogen, 9.46 grams; total energy, 428 cals.
Fuel value: 346 cals.; from protein, 70 p. ct.; from fat, 30 p. ct.

Time.	Average respiration rate.	Carbon dioxide.	Respiratory quotient.	Oxygen.	Average pulse rate.	Heat (computed).
		c.c.		*c.c.*		*cals.*
8^h36^m a.m.[1] . .	10	156	0.81	192	44	0.92
9 07 a.m. . .	10	141	.76	186	44	.88
9 48 a.m. . .	11	155	.82	188	45	.91

[1]Beefsteak eaten at 12 midnight July 13.

A similar experiment was made with the subject H. L. H., on July 15, 1911, in which 249 grams of beefsteak, with a nitrogen content of 11.44 grams, were eaten at midnight; beginning at 8^h59^m a. m. the next day, the metabolism was observed approximately every hour, the last observation being at 3^h16^m p. m. The results of the experiment are given in table 218. The calories per minute varied from 1.15 to 1.31, the highest value being found in the last period. Comparing these results with the basal heat production of 1.11 calories

found for this subject approximately two weeks previous, we note that the basal value was exceeded in all of the observations on July 15. This is in full conformity with the experiment of July 1, 1911, given in table 215, which showed that with this subject exactly the same amount of beefsteak had a prolonged effect which continued 12 hours or more.

TABLE 218.—*H. L. H., July 15, 1911. Lying.* (Values per minute.)

Beefsteak:

Amount, 249 grams; nitrogen, 11.44 grams; total energy, 518 cals.
Fuel value: Total, 418 cals.; from protein, 70 p. ct.; from fat, 30 p. ct.

Time.	Average respiration rate.	Carbon dioxide.	Respiratory quotient.	Oxygen.	Average pulse rate.	Heat (computed).
		c.c.		*c.c.*		*cals.*
8^h59^m a.m.[1].	16	190	0.75	255	60	1.21
9 41 a.m..	15	187	.76	247	60	1.17
10 25 a.m..	16	185	.76	243	58	1.15
11 08 a.m..	15	191	.76	250	59	1.19
12 11 p.m..	15	203	.76	266	64	1.26
12 58 p.m..	..	197	.78	253	62	1.21
2 12 p.m..	..	208	.78	268	65	1.28
3 16 p.m..	15	207	.75	277	67	1.31

[1]Beefsteak eaten between 12^h03^m and 12^h10^m a. m.

The nitrogen excretion for $14\frac{1}{2}$ hours after the ingestion of the beefsteak was as follows: Between 10^h30^m p. m., July 14, to 7^h40^m a. m., July 15, 0.67 gram per hour; between 7^h40^m a. m. and 2^h40^m p. m., July 15, 0.71 gram per hour. It is clear that these two experiments are not at all in agreement so far as the two subjects are concerned, and yet more nearly comparable experiments with H. L. H. than those of July 1 and July 15 can hardly be expected. With this subject, at least, 249 grams of beefsteak resulted in a stimulus to the metabolism which persisted 8 to 12 hours and probably somewhat longer.

A similar experiment was made with Dr. S.[1] on July 13, 1911 (details not here given), in which but 73 grams of beefsteak, with a nitrogen content of 3.36 grams, were eaten at midnight. The average heat production for three experimental periods the next morning between 9 and 10 o'clock was 0.92 calorie. This is the basal value for this subject; hence the only deduction that can be drawn is that the small amount of beefsteak was without influence upon the basal metabolism 9 hours after eating.

CONCLUSIONS AS TO THE EFFECT OF INGESTING BEEFSTEAK.

A study of the results obtained from all of the experiments in which beefsteak was ingested leads us to the conclusion that 200 grams of cooked steak, containing 8 to 10 grams of nitrogen, produce a rise in

[1]We desire to acknowledge the hearty cooperation of our colleague, Professor H. Monmouth Smith, who was a voluntary observer at the time these experiments were made.

the heat output of from 8 to 12 calories per hour for 6 to 12 hours, and that the total effect upon the heat output is not complete in 12 hours. The period of maximum rise in metabolism probably occurs within the first 4 hours, although a considerable increase may be found for a much longer period.[1]

GLIDINE.

In May 1910, five experiments were made with a vegetable protein substance called "glidine,"[2] which is claimed to be the gliadin of wheat. As will be seen from table 50 (page 124), this food material had a protein content of approximately 87 per cent. An unfortunate feature of the experiments with glidine was the fact that the subjects found it almost impossible to eat any considerable amount. The largest amount taken was 70 grams, which was used in two experiments; in three experiments the subject took only 45 grams. All the observations were made with the chair calorimeter. The statistical data not included n the tables or the discussion of the experiments are given here:

L. E. E., 8h40m a. m. to 3h19m p. m., May 3, 1910. 59.6 kilograms. 2 basal periods.—Basal periods ended 10h40m a. m.; food periods began 11h19m a. m. Subject unable to take a large amount of glidine without nausea. Urinated 6h30m, 8h47m, 10h45m a. m., 12h19m, 2h19m, 3h19m p. m. Drank 85 grams water 12h19m p. m. Asleep 12h04m p. m. to 12h12m p. m. and 1h32m p. m. to 2h08m p. m.; restless at other times. Rectal thermometer slipped out of position in third food period; temperature records not available after 12h19m p. m. Basal periods: body-temperature, 36.90°, 36.81°, 36.93° C.; pulse rate, 56; respiration rate, 16. Food periods: body-temperature, 36.92°, 36.94° C.; pulse rate, 55; respiration rate, 17.

L. E. E., 8h31m a. m. to 2h13m p. m., May 11, 1910. 59.2 kilograms. 2 basal periods.—Fasting periods ended at 10h31m a. m.; food periods began at 11h13m a. m. Subject defecated and urinated at 6h45m a. m.; urinated at 10h31m a. m. and 2h15m p. m. In first part of first basal period, there was a decided movement and subject was cautioned to keep quiet. Asleep at end of period; awakened at beginning of next period. Rectal thermometer not used after 1h17m p. m. Basal periods: pulse rate, 56; respiration rate, 17. Food periods: pulse rate, 57; respiration rate, 18.

J. J. C., 9h31m a. m. to 4h43m p. m., May 9, 1910. 64.5 kilograms. 2 basal periods.—Basal periods ended 11h31m a. m.; food periods began 12h43m p. m. Subject urinated 6h45m, 11h36m a. m., 3h53m, 4h55m p. m. Asleep 11h10m a. m., 1h28m p. m., 1h48m p. m. and was awakened. Basal periods: body-temperature, 36.6°, 36.69°, 36.7° C.; pulse rate, 60; respiration rate, 19. Food periods: body-temperature, 36.79°, 36.78°, 36.80°, 36.77°, 36.85° C.; pulse rate, 59; respiration rate, 19.

J. R., 8h38m a. m. to 3h22m p. m., May 5, 1910. 70.1 kilograms. 2 basal periods.—Basal periods ended 10h38m a. m.; food periods began 11h22m a. m. Urinated 7 a. m., 10h40m a. m., 3h30m p. m. Very sleepy during greater part

[1]It is of interest to note here that Aub and DuBois, in a recent research, found larger increases in the metabolism following the ingestion of beefsteak with abnormal individuals (a dwarf and a legless man) than with normal individuals of greater weight and body-surface area. (Aub and DuBois, Arch. Intern. Med., 1917, **19**, p. 840.)

[2]Street, Ann. Rept. Conn. Agr. Exp. Sta., 1913.

of afternoon and asleep just before 2^h22^m p. m. but awoke shortly afterwards. Basal periods: body-temperature, 37.01°, 37.01°, 37.09° C.; pulse rate, 65; respiration rate, 15. Food periods: body-temperature, 37.22°, 37.14°, 37.28°, 37.19°, 37.37° C.; pulse rate, 68; respiration rate, 15.

J. R., 8^h37^m a. m. to 3^h12^m p. m., May 10, 1910. 71.0 kilograms. 2 basal periods.—Basal periods ended 10^h37^m a. m.; food periods began 11^h12^m a. m. Subject felt chilly at first. Urinated 7 a. m., 10^h37^m a. m. and 2^h16^m p. m. Basal periods: body-temperature, 37.00°, 36.90°, 37.08° C.; pulse rate, 66; respiration rate, 16. Food periods: body-temperature, 37.23°, 37.56°, 37.47°, 37.38°, 37.46° C.; pulse rate, 75; respiration rate, 16.

DISCUSSION OF EXPERIMENTS.

L. E. E., May 3, 1910.—The subject took 45 grams of glidine suspended in 110 grams of water, with a nitrogen content of 6.24 grams; the results obtained are given in table 219. The basal value was found on the same day, immediately prior to the ingestion of the glidine. A marked increment in carbon-dioxide production and oxygen consumption was noted in all the periods of the experiment and an increase in heat production in the first two periods; in the last two periods the values for the heat production were within 1 calorie of the basal value.

TABLE 219.—*L. E. E., May 3, 1910. Sitting.* (1-hour periods.)

Glidine:[1]
Amount, 45 grams; nitrogen, 6.24 grams; total energy, 223 cals.
Fuel value: Total, 168 cals.; from protein, 95 p. ct.; from fat, 2 p. ct.; from carbohydrates, 3 p. ct.

Basal values (May 3, 1910): CO_2, 25 grams; O_2, 21.5 grams; heat[2], 78 cals.; respiratory quotient, 0.84. Nitrogen in urine, 0.51 gram per hour.

Time elapsed since subject finished eating.	Nitrogen in urine per hour.	Carbon dioxide.		Oxygen.		Heat.[2]		Respiratory quotient.
		Total.	Increase.	Total.	Increase.	Total.	Increase.	
	gram.	*grams.*	*grams.*	*grams.*	*grams.*	*cals.*	*cals.*	
½ to 1½ hours	0.52	27.0	2.0	25.5	4.0	80	2	0.76
1½ to 2½ hours	.70	31.5	6.5	27.5	6.0	87	9	.83
2½ to 3½ hours	.70	27.5	2.5	26.0	4.5	79	1	.77
3½ to 4½ hours	.66	28.5	3.5	25.5	4.0	79	1	.81
Total....	...	114.5	14.5	104.5	18.5	325	13	....

[1]Subject took glidine in 110 grams of water.
[2]Heat eliminated corrected for change in body-weight, but not for change in body-temperature.

L. E. E., May 11, 1910.—The same amount of glidine was taken as in the first experiment with this subject; the basal value was determined immediately before the observations with glidine. The results are given in table 220. Noticeable increments in the carbon-dioxide production and oxygen consumption were obtained in the three 1-hour periods, but relatively insignificant increments were found in the heat production. The absence of body-temperature measurements, with the

consequent impossibility of correcting for changes in body-temperature, may have accounted for this discrepancy. The nitrogen excretion per hour was less than in any of the periods of the former experiment. The increment in both the carbon-dioxide production and oxygen consumption is too great, however, not to be taken as a positive effect of the ingestion of the glidine.

TABLE 220.—*L. E. E., May 11, 1910. Sitting.* (1-hour periods.)

Glidine:[1]

Amount, 45 grams; nitrogen, 6.24 grams; total energy, 223 cals.

Fuel value: Total, 168 cals.; from protein, 95 p. ct.; from fat, 2 p. ct.; from carbohydrates, 3 p. ct.

Nitrogen in urine, 0.40 gram per hour.

Basal values (May 11, 1910): CO_2, 24.5 grams; O_2, 21.5 grams; heat,[2] 80 cals.; respiratory quotient, 0.83. Nitrogen in urine, 0.10 gram per hour.

Time elapsed since subject finished eating.	Carbon dioxide.		Oxygen.		Heat.[2]		Respiratory quotient.
	Total.	Increase.	Total.	Increase.	Total.	Increase.	
	grams.	*grams.*	*grams.*	*grams.*	*cals.*	*cals.*	
½ to 1½ hours	28.0	3.5	26.0	4.5	85	5	0.78
1½ to 2½ hours	29.0	4.5	25.5	4.0	81	1	.83
2½ to 3½ hours	29.5	5.0	26.0	4.5	79	−1	.82
Total...	86.5	13.0	77.5	13.0	245	5	....

[1]Subject took glidine in 200 grams of water.

[2]Heat eliminated corrected for change in body-weight, but not for change in body-temperature.

J. J. C., May 9, 1910.—A third experiment was made in which 45 grams of glidine were given, but with another subject. The results of this experiment are found in table 221, which shows a considerable increase in all the factors of the metabolism. Even at the end of the 4 hours there is no indication that the total increase due to the glidine had been obtained. The respiratory quotients are not far from those which would be expected during the combustion of protein, although it can be computed from the values obtained for the nitrogen excretion, which average 0.58 gram per hour, that the total calories from protein can be only about one-third of the total calories found, the remainder of the metabolism being derived from fat and carbohydrates.

J. R., May 5, 1910.—A larger amount of glidine was taken by this subject than in the three experiments previously discussed, the exact amount being 70 grams, with a nitrogen content of 9.70 grams. The measurements of the metabolism are given in table 222. The oxygen consumption during the second period could not be obtained, but noticeable increments were found in the other periods and also for carbon-dioxide production and heat production in all the periods. It is evident that the effect of the ingestion of this amount of glidine

TABLE 221.—*J. J. C., May 9, 1910. Sitting.* (1-hour periods.)

Glidine:[1]

Amount, 45 grams; nitrogen, 6.24 grams; total energy, 223 cals.

Fuel value: Total, 168 cals.; from protein, 95 p. ct.; from fat, 2 p. ct.; from carbohydrates, 3 p. ct.

Basal values: CO_2, 24.5 grams (May 9, 1910); O_2, 21 grams (March 4 to May 31, 1910); heat (computed), 72 cals. (May 9, 1910). Nitrogen in urine, 0.26 gram per hour (May 9, 1910).

Time elapsed since subject finished eating.	Nitrogen in urine per hour.	Carbon dioxide.		Oxygen.		Heat (computed).		Respiratory quotient.
		Total.	Increase.	Total.	Increase.	Total.	Increase.	
	gram.	*grams.*	*grams.*	*grams.*	*grams.*	*cals.*	*cals.*	
1 to 2 hours...	0.57	28.5	4.0	25.0	4.0	83	11	0.82
2 to 3 hours...	.57	26.0	1.5	24.0	3.0	79	7	.79
3 to 4 hours...	.57	27.5	3.0	25.0	4.0	83	11	.79
4 to 5 hours...	.61	26.5	2.0	24.5	3.5	81	9	.78
Total....	...	108.5	10.5	98.5	14.5	326	38	....

[1]Subject took glidine in 164 grams of water.

was considerable. As the basal values were determined on the same day as the metabolism after glidine, there can be no uncertainty as to the validity of the increments.

TABLE 222.—*J. R., May 5, 1910. Sitting.* (1-hour periods.)

Glidine:[1]

Amount, 70 grams; nitrogen, 9.70 grams; total energy, 347 cals.

Fuel value: Total, 262 cals.; from protein, 95 p. ct.; from fat, 2 p. ct.; from carbohydrates, 3 p. ct.

Nitrogen in urine, 0.83 gram per hour.

Basal values (May 5, 1910): CO_2, 27 grams; O_2, 23 grams; heat,[2] 73 cals.; respiratory quotient 0.86. Nitrogen in urine, 0.44 gram per hour.

Time elapsed since subject finished eating.	Carbon dioxide.		Oxygen.		Heat.[2]		Respiratory quotient.
	Total.	Increase.	Total.	Increase.	Total.	Increase.	
	grams.	*grams.*	*grams.*	*grams.*	*cals.*	*cals.*	
½ to 1½ hours.....	31.5	4.5	28.0	5.0	78	5	0.82
1½ to 2½ hours.....	33.0	6.0	....	...	96	23	....
2½ to 3½ hours.....	30.0	3.0	25.0	2.0	84	11	.88
3½ to 4½ hours.....	29.5	2.5	28.5	5.5	85	12	.76
Total.....	124.0	16.0	81.5	12.5[3]	343	51	....

[1]Taken in 200 grams of water.

[2]Heat eliminated corrected for change in body-weight, but not for change in body-temperature.

[3]Increment of oxygen for a total of 3 hours.

J. R., May 10, 1910.—The same amount of glidine was taken in this second experiment with J. R. as in that of May 5, and the results are therefore comparable. Increments in the carbon-dioxide excretion, oxygen consumption, and heat production were also found in this exper-

iment, with no indication of a cessation in the stimulus at the end of the experiment. (See table 223.) The 70 grams of glidine therefore had a pronounced effect, which continued 4 hours, if not longer. The nitrogen excretion was strikingly lower in this experiment, but in any event the total energy from the protein katabolized can be but a relatively small part of the total heat production, probably about one-third.

TABLE 223.—*J. R., May 10, 1910. Sitting.* (1-hour periods.)

Glidine:[1]

Amounts, 70 grams glidine, 20 grams lemon juice; nitrogen, 9.70 grams; total energy, 352 cals.

Fuel value: Total, 267 cals.; from protein, 93 p. ct.; from fat, 2 p. ct.; from carbohydrates, 5 p. ct.

Nitrogen in urine, 0.72 gram per hour (in first three periods).

Basal values: CO_2, 27.5 grams (May 10, 1910); O_2, 22.5 grams (March 21 to May 13, 1910); heat, 72 cals. (May 10, 1910). Nitrogen in urine, 0.44 gram per hour (May 10, 1910).

Time elapsed since subject finished eating.	Carbon dioxide.		Oxygen.		Heat.		Respiratory quotient.
	Total.	Increase.	Total.	Increase.	Total.	Increase.	
	grams.	*grams.*	*grams.*	*grams.*	*cals.*	*cals.*	
¼ to 1¼ hours.....	30.5	3.0	26.0	3.5	76	4	0.86
1¼ to 2¼ hours.....	33.0	5.5	28.0	5.5	83	11	.86
2¼ to 3¼ hours.....	33.0	5.5	28.0	5.5	85	13	.85
3¼ to 4¼ hours.....	33.0	5.5	27.5	5.0	84	12	.87
Total.....	129.5	19.5	109.5	19.5	328	40	....

[1]Taken with lemon juice and 400 grams of water.

CONCLUSIONS AS TO EFFECT OF INGESTING GLIDINE.

An examination of the results obtained in this series of five experiments with glidine shows that it produced a marked effect upon the metabolism even when such small amounts were taken as 45 grams, with a nitrogen content of approximately 6.25 grams. The two experiments with J. R., in which 70 grams were taken, gave a much larger increment and a more prolonged effect than the smaller amount. A comparison of these results with glidine and those obtained with other predominatingly protein diets will be made subsequently.

GLUTEN BREAD AND SKIM MILK.

In some of the earliest experiments in this study a special gluten bread was used which was made in the laboratory and contained a minimum amount of carbohydrate. As much of this bread as possible was taken by the subject, skim milk being added in minimum amounts to aid in its ingestion, as the bread was very dry and somewhat unpalatable. The experiments were carried out with the Middletown respiration calorimeter in May 1906, there being in all four experi-

ments with two subjects. The observations were made in 2-hour periods. The basal values were all determined on a different day from that on which the metabolism after gluten was determined. The amount of gluten bread taken in the last experiment by the second subject, H. C. K., was considerably smaller than the amounts eaten by the subject H. R. D.; H. C. K. also found it necessary to take a greater quantity of skim milk with the bread. The proportion of nitrogen from the skim milk was therefore increased, but the experiment is included in this section for additional information as to the metabolism after the ingestion of gluten bread. Statistical data not included in the tables or in the discussion of the experiments are given here:

H. R. D., 9h01m a. m. to 5h01m p. m., May 2, 1906. 58.5 kilograms.—Urinated at 7h05m a. m. and at beginning of every period. Quiet for most part during experiment; drowsy between 9 a. m. and 10 a. m.; especially quiet about 11.30 a. m.; read about three-fourths of time. Body-temperature: 36.71°, 36.70°, 36.71°, 36.76°, 36.73° C. Pulse rate, 67; respiration rate, 19.

H. R. D., 9h30m a. m. to 9h30m p. m., May 9, 1906. 58.4 kilograms.—Took enema and urinated about 7h30m a. m. and urinated at beginning of every period. Distressed by rectal thermometer owing to temporary tenderness in lower part of rectum; removed thermometer at 10h31m a. m. and exchanged it for another, telephoning once and opening food aperture twice for the purpose; rest of time quiet and reading through first and second periods. Sat idle from 1h30m p. m. to 2h04m p. m., slept from 2h04m p. m. to 2h32m p. m., read from 2h34m p. m. to 9h30m p. m.; drowsy at times during day. Body-temperature: no record at beginning of experiment; subsequent records, 36.85°, 37°, 36.95°, 36.95°, 37.02°, 36.78° C. Pulse rate, 63; respiration rate, 19.

H. R. D., 9h10m a. m. to 9h10m p. m., May 17, 1906. 59.1 kilograms.—Urinated 7h15m a. m. (after enema) and also at beginning of every period. Sat quietly reading almost whole experiment. Drank 90 grams water at 11h10m a. m. Body-temperature: 36.64°, 36.62°, 36.71°, 36.53°, 36.59°, 36.60° C. Pulse rate, 69; respiration rate, 20.

H. C. K., 9h10m a. m. to 5h10m p. m., May 7, 1906. 74.4 kilograms.—Urinated and defecated about 7h10m a. m. and urinated at beginning of every period. Food difficult to swallow. Subject very quiet throughout experiment; fell asleep twice in second period, but not drowsy rest of time; read during most of experiment. Body-temperature: 36.34°, 36.38°, 36.53°, 36.60°, 36.66° C.; no record at end of experiment. Pulse rate, 50; respiration rate, 19.

DISCUSSION OF EXPERIMENTS.

H. R. D., May 2, 1906.—In the first experiment with this subject 100 grams of gluten bread were taken and 221 grams of skim milk. The nitrogen content of the diet was 15.43 grams, the greater part of this being contained in the gluten bread. During the 8 hours of the experiment, the results of which are given in table 224, there was a continuously increasing rise in the nitrogen excretion, also an increment in all of the factors of the metabolism. The maximum carbon-dioxide production was in the third period, as was also the maximum heat production. It was necessary for experimental reasons to com-

bine the results obtained for the oxygen consumption in the second and third periods in which the highest increment was found. Since the measured metabolism was distinctly above the basal metabolism in the fourth period, it is evident that the influence of the ingestion of food had not ceased at the end of the experiment.

TABLE 224.—*H. R. D., May 2, 1906. Sitting.* (2-hour periods.)

Gluten bread and skim milk:

Amounts, 100 grams gluten bread, 221 grams skim milk; nitrogen, 15.43 grams; total energy, 631 cals.

Fuel value: Total, 496 cals.; from protein, 84 p. ct.; from fat, 2 p. ct.; from carbohydrates, 14 p. ct.

Basal values (February 6 to April 20, 1906): CO_2, 47 grams; O_2, 42 grams; heat, 146 cals. Nitrogen in urine, 0.36 gram per 2 hours (May 2, 1906).

Time elapsed since subject finished eating.[1]	Nitrogen in urine per 2 hours.	Carbon dioxide.		Oxygen.		Heat.		Respiratory quotient.
		Total.	Increase.	Total.	Increase.	Total.	Increase.	
	grams.	*grams.*	*grams.*	*grams.*	*grams.*	*cals.*	*cals.*	
0 to 2 hours...	0.79	53	6	47	5	157	11	0.81
2 to 4 hours...	1.29	53	6	95	11	157	11	.96
4 to 6 hours...	1.65	59	12			164	18	.78
6 to 8 hours...	1.92	52	5	48	6	157	11	.78
Total....	....	217	29	190	22	635	51	....

[1]Subject ate food in 21 minutes.

H. R. D., May 9, 1906.—The amounts of gluten bread and skim milk taken in this experiment were practically the same as those taken in the first experiment with this subject, but the total period of observation was lengthened in order to obtain the final effect of the ingested food. The results are given in table 225, from which it will be seen that the basal value was reached in the fifth period, both carbon-dioxide production and heat production showing values somewhat less than basal in the sixth period. In other respects the experiment is a duplicate of that of May 2. The nitrogen excretion reached the maximum in the fourth period and decreased thereafter. It is of interest to note that, although the nitrogen in the sixth period was considerably above the basal value, the carbon-dioxide excretion, oxygen consumption, and heat production had already reached the basal value or had fallen slightly below in this period.

H. R. D., May 17, 1906.—The third experiment with this subject was made with a considerably larger amount of gluten bread, but the amount of skim milk was also increased. The total nitrogen intake was 24.47 grams, of which 21.88 grams came from gluten bread and 2.59 grams from skim milk. This experiment was also continued for 12 hours; the results are given in table 226. The increment in all the factors of the metabolism was noticeable; the base-line was not reached

TABLE 225.—*H. R. D., May 9, 1906. Sitting.* (2-hour periods.)

Gluten bread and skim milk:

Amounts, 100 grams gluten bread, 220 grams skim milk; nitrogen, 15.42 grams; total energy, 622 cals.

Fuel value: Total, 487 cals.; from protein, 84 p. ct.; from fat, 2 p. ct.; from carbohydrates, 14 p. ct.

Basal values (February 6 to April 20, 1906): CO_2, 47 grams; O_2, 42 grams; heat, 146 cals. Nitrogen in urine, 0.44 gram per 2 hours (May 9, 1906).

Time elapsed since subject finished eating.	Nitrogen in urine per 2 hours.	Carbon dioxide.		Oxygen.		Heat.		Respiratory quotient.
		Total.	Increase.	Total.	Increase.	Total.	Increase.	
	grams.	*grams.*	*grams.*	*grams.*	*grams.*	*cals.*	*cals.*	
0 to 2 hours	0.80	59	12	53	11	174[1]	28	0.82
2 to 4 hours	1.51	56	9	52	10	173	27	.78
4 to 6 hours	1.66	52	5	50	8	155	9	.76
6 to 8 hours	2.12	53	6	46	4	156	10	.84
8 to 10 hours	1.59	49	2	44	2	158	12	.81
10 to 12 hours	1.09	45	−2	42	0	136	−10	.78
Total....	....	314	32	287	35	952	76	....

[1]Heat eliminated not corrected for small change in body-weight or for change in body-temperature.

TABLE 226.—*H. R. D., May 17, 1906. Sitting.* (2-hour periods.)

Gluten bread and skim milk:

Amounts, 153 grams gluten bread, 499 grams skim milk; nitrogen, 24.47 grams; total energy, 1,023 cals.

Fuel value: Total, 809 cals.; from protein, 81 p. ct.; from fat, 2 p. ct.; from carbohydrates, 17 p. ct.

Basal values (February 6 to April 20, 1906): CO_2, 47 grams; O_2, 42 grams; heat, 146 cals. Nitrogen in urine, 0.58 gram per 2 hours (May 17, 1906).

Time elapsed since subject finished eating.[1]	Nitrogen in urine per 2 hours.	Carbon dioxide.		Oxygen.		Heat.		Respiratory quotient.
		Total.	Increase.	Total.	Increase.	Total.	Increase.	
	grams.	*grams.*	*grams.*	*grams.*	*grams.*	*cals.*	*cals.*	
0 to 2 hours	1.29	59	12	45	3	179	33	0.97
2 to 4 hours	1.97	61	14	50	8	176	30	.89
4 to 6 hours	2.51	63	16	54	12	165	19	.85
6 to 8 hours	2.87	60	13	49	7	174	28	.90
8 to 10 hours	2.69	53	6	45	3	163	17	.86
10 to 12 hours	2.10	52	5	49	7	[2]162	16	.77
Total....	....	348	66	292	40	1,019	143	....

[1]Subject ate food in 39 minutes.

[2]Heat eliminated corrected for change in body-weight, but not for change in body-temperature.

at the end of the experiment. The maximum in nitrogen excretion was obtained in the fourth period, but although there was a tendency for it to decrease thereafter the output was very large even in the sixth period, showing a considerable metabolism of nitrogenous material. The ingestion of 24.47 grams of nitrogen, therefore, had a pronounced

effect upon the metabolism, which persisted for the 12 hours of the experiment and showed no indication of ceasing at the end of that time. If we compare the results with those obtained in the preceding experiment, we find the increment in carbon-dioxide production is considerably larger in this experiment and that the increment in heat production is practically twice as large, but that the increment in oxygen consumption is not far from the same in both experiments. This indicates a disparity between the direct and indirect calorimetry, which unfortunately is only too frequent in experiments of this kind.

H. C. K., May 7, 1906.—Only 66 grams of gluten bread were taken in this experiment with 706 grams of skim milk. The nitrogen content of the diet was 13.04 grams, of which 9.44 grams were contained in the gluten bread. The basal values were determined but 4 days previous to the experiment and were thus approximately correct values for use in this experiment. Relatively large increments are shown in table 227 throughout the experimental period. The nitrogen excretion increased for the first three periods, but decreased slightly in the last period. Both the nitrogen excretion and the total metabolism indicate that the effect of ingesting this protein food material was still felt at the end of the experiment.

TABLE 227.—*H. C. K., May 7, 1906. Sitting.* (2-hour periods.)

Gluten bread and skim milk:
Amounts, 66 grams gluten bread, 706 grams skim milk; nitrogen, 13.04 grams; total energy, 672 cals.
Fuel value: Total, 558 cals.; from protein, 65 p. ct.; from fat, 4 p. ct.; from carbohydrates, 31 p. ct.
Basal values (May 3, 1906): CO_2, 51 grams; O_2, 47 grams; heat, 164 cals. Nitrogen in urine, 1 gram per 2 hours (May 7, 1906).

Time elapsed since subject finished eating.[1]	Nitrogen in urine per 2 hours.	Carbon dioxide.		Oxygen.		Heat.		Respiratory quotient.
		Total.	Increase.	Total.	Increase.	Total.	Increase.	
	grams.	*grams.*	*grams.*	*grams.*	*grams.*	*cals.*	*cals.*	
0 to 2 hours...	1.22	60	9	56	9	177	13	0.78
2 to 4 hours...	1.63	61	10	56	9	177	13	.79
4 to 6 hours...	2.09	65	14	53	6	179	15	.90
6 to 8 hours...	1.87	57	6	56	9	178	14	.73
Total....	....	243	39	221	33	711	55	....

[1]Subject ate food in 37 minutes.

CONCLUSIONS AS TO EFFECT OF INGESTING GLUTEN.

The four experiments with gluten bread and skim milk all indicate a pronounced increment in the metabolism following the ingestion of the food, which in some instances continued for a 12-hour experimental period. This increment was shown not only in the gaseous metabolism and heat production, but also in the nitrogen excretion, which was

considerably above the basal value even at the end of the experiment. In three of the four experiments the nitrogen excretion in the urine was the highest in the third 2-hour period of the experiment. There was a distinct tendency, however, for the greatest increase in the heat output to occur in the first 4 hours of the experiment.

PLASMON AND SKIM MILK.

The glidine used in the protein experiments represented an approximately pure vegetable protein; the gluten was also a vegetable protein. To study the effect of an animal protein, plasmon, a food material derived from milk, was given to the subject in two experiments. Bo experiments were made with the Middletown respiration calorimet in 2-hour periods.

H. R. D., May 4, 1906.—In addition to 100 grams of plasmon, the subject took 70 grams of plasmon milk biscuit and 206 grams of skim milk. The total nitrogen intake was 15.07 grams, of which 11.92 grams came from the plasmon, 2.10 grams from the plasmon milk biscuit, and 1.05 grams from the skim milk. With this diet 36 per cent of the fuel value of the intake was derived from carbohydrates and but 54 per cent from protein. The basal value employed was the average of determinations made between February 6 and April 20 of the same year. As may be seen from table 228, an increment in carbon-dioxide excretion was found in all four periods. The measurement of oxygen consumption was not obtained for the first period, but subsequently a pronounced increment was observed. The heat production also increased in the four periods and the nitrogen excretion was very

TABLE 228.—*H. R. D., May 4, 1906. Sitting.* (2-hour periods.)

Plasmon, plasmon milk biscuit, and skim milk:
Amounts, 100 grams plasmon, 70 grams plasmon milk biscuit, 206 grams skim milk; nitrogen, 15.07 grams; total energy, 890 cals.
Fuel value: Total, 758 cals.; from protein, 54 p. ct.; from fat, 10 p. ct.; from carbohydrates, 36 p. ct.
Basal values (February 6 to April 20, 1906): CO_2, 47 grams; O_2, 42 grams; heat, 146 cals. Nitrogen in urine, 0.77 gram per 2 hours (May 4, 1906).

Time elapsed since subject finished eating.[1]	Nitrogen in urine per 2 hours.	Carbon dioxide.		Oxygen.		Heat.		Respiratory quotient.
		Total.	Increase.	Total.	Increase.	Total.	Increase.	
	grams.	*grams.*	*grams.*	*grams.*	*grams.*	*cals.*	*cals.*	
0 to 2 hours...	1.58	61	14	...	..	172	26	....
2 to 4 hours...	2.12	62	15	54	12	177	31	0.83
4 to 6 hours...	2.14	56	9	47	5	153	7	.87
6 to 8 hours...	1.81	55	8	52	10	159	13	.76
Total....	....	234	46	153	[2]27	661	77	....

[1]Subject ate food in 36 minutes. [2]Increment of oxygen 2 to 8 hours after food.

considerably increased. The body-temperature approximated 36.7° C.; the pulse rate averaged 65 and the respiration rate 19. The ingestion of the 15 grams of nitrogen in this diet thus resulted in a pronounced increase in the metabolism, which continued for at least 8 hours.

H. C. K., May 15, 1906.—Plasmon graham biscuit was substituted for the milk biscuit used in the previous experiment, the amounts being 100 grams plasmon, 47 grams plasmon graham biscuit, and 439 grams skim milk. The total nitrogen intake was practically the same as in the first experiment, *i. e.*, 15.25 grams, with 11.92 grams from the plasmon, 1.07 grams from the biscuit, and 2.26 grams from the skim milk. The experiment was lengthened to 12 hours in order to obtain the total effect of the food. The results of the experiment are given in table 229, which shows that the increment in carbon-dioxide production persists throughout the entire experiment. The values obtained for oxygen consumption were variable, as is indicated by the great irregularity in the respiratory quotients. The possibility of a compensation can hardly be considered here and the variations are undoubtedly due to some technical difficulty. The measurements of the heat production show positive increments during the first three periods, with values lower than basal in the fourth period, an increment in the fifth period, and a value lower than basal in the sixth period. The nitrogen values are characteristic, with a maximum in the third period. The body-temperature averaged 36.7° C.; the pulse rate averaged 51 and the respiration rate 18. Unfortunately the results obtained in this experiment do not permit definite conclusions regarding

TABLE 229.—*H. C. K., May 15, 1906. Sitting.* (2-hour periods.)

Plasmon, plasmon graham biscuit, skim milk:

Amounts, 100 grams plasmon, 47 grams plasmon graham biscuit, 439 grams skim milk; nitrogen, 15.25 grams; total energy, 862 cals.

Fuel value: Total, 728 cals.; from protein, 56 p. ct.; from fat, 8 p. ct.; from carbohydrates, 36 p. ct.

Basal values (May 3, 1906): CO_2, 51 grams; O_2, 47 grams; heat, 164 cals. Nitrogen in urine, 0.97 gram per 2 hours (May 15, 1906).[1]

Time elapsed since subject finished eating.[2]	Nitrogen in urine per 2 hours.	Carbon dioxide.		Oxygen.		Heat.		Respiratory quotient.
		Total.	Increase.	Total.	Increase.	Total.	Increase.	
	grams.	*grams.*	*grams.*	*grams.*	*grams.*	*cals.*	*cals.*	
½ to 2½ hours	1.53	62	11	59	12	191	27	0.77
2½ to 4½ hours	1.86	66	15	47	0	179	15	1.01
4½ to 6½ hours	2.04	63	12	58	11	178	14	.79
6½ to 8½ hours	1.79	53	2	50	3	160	−4	.76
8½ to 10½ hours	1.63	54	3	39	−8	180	16	1.01
10½ to 12½ hours	1.38	57	6	53	6	158	−6	.79
Total....	....	355	49	306	24	1,046	62	....

[1]Sample included amount for about 1 hour from the time subject began to eat food.

[2]Subject ate food in 34 minutes.

either the amount or the duration of the effect upon the metabolism due to the ingestion of this amount of nitrogen. The general effect of 100 grams or more of plasmon, together with 200 c.c. or over of skim milk, is to increase the heat output considerably above the basal metabolism for at least 10 hours.

SUMMARY OF RESULTS OF EXPERIMENTS ON INGESTION OF PROTEIN.

A general examination of the details of the experiments discussed in the preceding part of this section shows conclusively that following the ingestion of protein there is a distinct increase in the metabolism which may persist for a considerable period of time. In an attempt to establish a quantitative relationship between the amounts of protein ingested and the subsequent increments in the metabolism, and likewise to study the time relations, we have summarized in table 230 the results of the calorimeter experiments. The data for heat production in the respiration experiments have already been presented in table 215. (See page 284.)

Most of the experiments were made with animal protein, these including the large number in which beefsteak was ingested. Even the beefsteak experiments in which small amounts of bread and potato chips were taken may, for reasons previously discussed, be considered as primarily animal-protein experiments. The experiments with plasmon and skim milk likewise showed the influence of animal protein upon the metabolism. In the experiments with gluten bread and skim milk the effect of a combination of vegetable and animal proteins was studied, but the greater part of the nitrogen was supplied by the gluten. The only experiments with pure vegetable protein were those with glidine, but with two exceptions the amounts of nitrogen in the glidine ingested were relatively small.

It is somewhat difficult to present in tabular form the results of experiments extending over a period of many years, which were made with different apparatus, very considerably different amounts of food, and varying experimental periods. The table is, however, reasonably self-explanatory. Special attention should be called to the considerable variations in the length of the individual periods in the experiments, these being shown in the first column with the initials of the subject. In all cases they were 2 hours, 1 hour, or 45 minutes in length. The total increments in carbon-dioxide production, oxygen consumption, and heat production during the entire period of observation are given in the next to the last column; in the last column may be found the percentages of increment above the basal values for the same peri

A positive increment was obtained in all of the experiments except in that with F. M. M., January 20, 1910. Even in this experiment

TABLE 230.—*Summary of results of protein experiments with the respiration calorimeter.*

Food material, date, subject, and length of period.	Amount eaten.	Nitrogen in food.	Factor measured.	Basal value per period.	Increase over basal in period.								Total basal value for period of observation.	Total increase.	
					1	2	3	4	5	6	7	8		Amount.	Per cent.
Beefsteak.	*grams.*	*grams.*													
Apr. 5, 1907.... A. H. M., 2 hrs..	777	35.68	CO_2 (gm.)..	51	20	13	18	12	....	....	....	....	204	63	31
			O_2 (gm.)..	46	16	8	13	9	....	....	....	....	184	46	25
			Heat (cals.).	164	31	29	41	35	....	....	....	....	656	136	21
Apr. 6, 1907.... A. W. W., 2 hrs..	755	34.67	CO_2 (gm.)..	50	10	12	13	10	....	....	....	....	200	45	23
			O_2 (gm.)..	41	6	16	11	12	....	....	....	....	164	45	27
			Heat (cals.).	155	−3	26	32	37	....	....	....	....	620	92	15
May 24, 1907... A. H. M., 2 hrs..	384	17.63	CO_2 (gm.)..	51	9	14	4	1	....	....	....	....	204	28	14
			O_2 (gm.)..	46	2	9	6	0	....	....	....	....	184	17	9
			Heat (cals.).	164	24	27	19	0	....	....	....	....	656	70	11
May 25, 1907... A. W. W., 2 hrs..	373	18.62	CO_2 (gm.)..	50	7	5	9	−1	....	....	....	....	200	20	10
			O_2 (gm.)..	41	10	10	13	−1	....	....	....	....	164	32	20
			Heat (cals.).	155	16	16	18	−5	....	....	....	....	620	45	7
Dec. 4, 1908.... J. R., 1 hr.....	418	15.30	CO_2 (gm.)..	26.5	6.5	4.0	7.0	4.5	4.0	2.0	2.0	1.5	212.0	31.5	15
			O_2 (gm.)..	23.5	5.0	3.5	9.0	3.0	2.5	2.0	2.5	4.0	188.0	31.5	17
			Heat (cals.).	74	21	10	19	13	12	10	9	10	592	104	18
Dec. 10, 1908... F. M. M., 1 hr...	217	9.97	CO_2 (gm.)..	25.0	5.5	4.5	3.0	1.0	0.5	1.5	1.0	1.5	200.0	18.5	9
			O_2 (gm.)..	21.0	7.0	1.5	5.5	3.5	0.5	5.0	4.0	3.5	168.0	30.5	18
			Heat (cals.).	77	14	2	8	1	−2	5	−6	2	616	24	4
Dec. 23, 1908... F. M. M., 1 hr..	208	9.55	CO_2 (gm.)..	25.5	4.5	3.0	4.5	−0.5	2.5	0.5	....	....	153.0	14.5	9
			O_2 (gm.)..	22.5	2.0	2.0	1.5	−1.5	1.5	0.0	....	....	135.0	5.5	4
			Heat (cals.).	75	5	0.0	7	2	3	0.0	....	....	450	17	4
Jan. 20, 1910.... F. M. M., 1 hr...	132	6.05	CO_2 (gm.)..	26.5	3.5	2.5	−2.5	−2.5	−2.5	−1.0	....	....	[1]150.0	[1]−0.5	0
			O_2 (gm.)..	23.0	2.0	2.0	−1.0	−1.0	−1.0	−1.0	....	....	[1]130.5	[1]−1.0	−1
			Heat (cals.).	80	5	4	3	3	3	−6	....	....	[1]453	[1]10	2
Jan. 17, 1910.... L. E. E., 1 hr...	163	7.20	CO_2 (gm.)..	25.5	3.0	3.5	2.0	1.5	2.5	....	....	....	127.5	12.5	10
			O_2 (gm.)..	21.5	2.5	3.0	3.0	4.0	5.0	....	....	....	107.5	17.5	16
			Heat (cals.).	76	13	7	10	5	12	....	....	....	380	47	12
Beefsteak and bread.															
Jan. 11, 1910.... F. M. M., 1 hr..	246 (steak) 50 (bread)	10.79	CO_2 (gm.)..	26.5	4.0	3.5	2.5	2.5	1.0	....	....	....	132.5	13.5	10
			O_2 (gm.)..	23.0	4.5	1.5	2.0	4.5	1.0	....	....	....	115.0	13.5	12
			Heat (cals.).	80	9	13	9	3	10	....	....	....	400	44	11

Jan. 12, 1910....	199 (steak).....	8.91	CO_2 (gm.)..	26.5	7.0	4.0	0.5	1.0	0.5	....	....	....	132.5	13.0	10
F. M. M., 1 hr..	38 (bread).....		O_2 (gm.)..	23.0	4.5	5.5	−2.5	2.0	1.0	....	....	....	115.0	10.5	9
			Heat (cals.).	80	8	16	0.0	6	2	....	....	....	400	32	8
Jan. 14, 1910....	201 (steak).....	9.55	CO_2 (gm.)..	26.5	6.0	6.0	4.0	2.5	3.0	....	....	....	132.5	21.5	16
F. M. M., 1 hr..	24 (bread).....		O_2 (gm.)..	23.0	2.0	6.0	3.5	1.0	6.5	....	....	....	115.0	19.0	17
			Heat (cals.).	80	12	13	12	5	4	....	....	....	400	46	12
Beefsteak and potato chips.															
Jan. 17, 1911....	193 (steak).....	8.99	CO_2 (gm.)..	19.5	2.5	2.0	2.0	3.0	....	....	....	....	78.0	9.5	12
J. J. C., 45 mins..	20 (potato chips).		O_2 (gm.)..	18.0	1.5	1.5	3.5	2.0	....	....	....	....	72.0	8.5	12
			Heat (cals.).	60	6	5	10	7	....	....	....	....	240	28	12
May 11, 1911...	270 (steak).....	12.67	CO_2 (gm.)..	17.0	4.5	2.5	2.0	1.5	0.0	0.5	0.0	0.0	136.0	11.0	8
J. J. C., 45 mins..	41 (potato chips).		O_2 (gm.)..	14.0	3.0	4.0	2.0	2.0	1.5	2.5	0.0	2.5	112.0	17.5	16
			Heat (cals.).	49	7	12	6	12	8	7	−6	−3	392	43	11
Jan. 18, 1911....	213 (steak).....	9.91	CO_2 (gm.)..	16.5	0.5	1.0	2.5	1.0	....	....	....	....	66.0	5.0	8
C. H. H., 45 mins.	20 (potato chips).		O_2 (gm.)..	15.0	1.0	0.5	2.5	1.0	....	....	....	....	60.0	5.0	8
			Heat (cals.).	45	3	4	5	3	....	....	....	....	180	15	8
Jan. 21, 1911....	215 (steak).....	10.00	CO_2 (gm.)..	22.0	0.5	1.5	1.0	0	....	....	....	....	88.0	3.0	3
V. G., 45 mins..	20 (potato chips).		O_2 (gm.)..	19.0	1.5	4.0	0.0	2.0	....	....	....	....	76.0	7.5	10
			Heat (cals.).	64	4	11	1	5	....	....	....	....	256	21	8
Jan. 23, 1911....	272 (steak).....	12.63	CO_2 (gm.)..	18.0	1.5	2.5	3.5	2.5	....	....	....	....	72.0	10.0	14
A. G. E., 45 mins.	20 (potato chips).		O_2 (gm.)..	16.0	2.5	1.5	4.0	1.5	....	....	....	....	64.0	9.5	15
			Heat (cals.).	53	2	3	5	2	....	....	....	....	212	12	6
Glidine.															
May 3, 1910....	45.....	6.24	CO_2 (gm.)..	25.0	2.0	6.5	2.5	3.5	....	....	....	....	100.0	14.5	15
L. E. E., 1 hr....			O_2 (gm.)..	21.5	4.0	6.0	4.5	4.0	....	....	....	....	86.0	18.5	22
			Heat (cals.).	78	2	9	1	1	....	....	....	....	312	13	4
May 11, 1910...	45.....	6.24	CO_2 (gm.)..	24.5	3.5	4.5	5.0	....	....	....	....	....	73.5	13.0	18
L. E. E., 1 hr....			O_2 (gm.)..	21.5	4.5	4.0	4.5	....	....	....	....	....	64.5	13.0	20
			Heat (cals.).	80	5	1	−1	....	....	....	....	....	240	5	2
May 5, 1910....	70.....	9.70	CO_2 (gm.)..	27.0	4.5	6.0	3.0	2.5	....	....	....	....	108.0	16.0	15
J. R., 1 hr.....			O_2 (gm.)..	23.0	5.0	....	2.0	5.5	....	....	....	....	[2]69.0	[2]12.5	18
			Heat (cals.).	73	5	23	11	12	....	....	....	....	292	51	17
May 9, 1910....	45.....	6.24	CO_2 (gm.)..	24.5	4.0	1.5	3.0	2.0	....	....	....	....	98.0	10.5	11
J. J. C., 1 hr.....			O_2 (gm.)..	21.0	4.0	3.0	4.0	3.5	....	....	....	....	84.0	14.5	17
			Heat (cals.).	72	11	7	11	9	....	....	....	....	288	38	13
May 10, 1910...	70.....	9.70	CO_2 (gm.)..	27.5	3.0	5.5	5.5	5.5	....	....	....	....	110.0	19.5	18
J. R., 1 hr.....			O_2 (gm.)..	22.5	3.5	5.5	5.5	5.0	....	....	....	....	90.0	19.5	22
			Heat (cals.).	72	4	11	13	12	....	....	....	....	288	40	14

[1]Total increase and total basal value are for actual duration of the experiment, *i. e.*, 5 hours 40 minutes.
[2]Total increase and total basal value for oxygen are for 3 hours; the oxygen was lost in second period.

TABLE 230. (continued).—*Summary of results of protein experiments with the respiration calorimeter.*

Food material, date, subject, and length of period.	Amount eaten.	Nitrogen in food.	Factor measured.	Basal value per period.	Increase over basal in period.								Total basal value for period of observation.	Total increase.	
					1	2	3	4	5	6	7	8		Amount	Per cent.
Gluten bread and skim milk.	*grams.*	*grams.*													
May 2, 1906....	100 (gluten bread).	15.43	CO_2 (gm.)..	47	6	6	12	5	....	....	....	....	188	29	15
H. R. D., 2 hrs...	221 (skim milk)....		O_2 (gm.)..	42	5	[1]5.5	[1]5.5	6	....	....	....	....	168	22	13
			Heat (cals.).	146	11	11	18	11	....	....	....	....	584	51	9
May 9, 1906....	100 (gluten bread).	15.42	CO_2 (gm.)..	47	12	9	5	6	2	−2	....	....	282	32	11
H. R. D., 2 hrs...	220 (skim milk)...		O_2 (gm.)..	42	11	10	8	4	2	0	....	....	252	35	14
			Heat (cals.).	146	28	27	9	10	12	−10	....	....	876	76	9
May 17, 1906...	153 (gluten bread).	24.47	CO_2 (gm.)..	47	12	14	16	13	6	5	....	....	282	66	23
H. R. D., 2 hrs...	499 (skim milk)...		O_2 (gm.)..	42	3	8	12	7	3	7	....	....	252	40	16
			Heat (cals.).	146	33	30	19	28	17	16	....	....	876	143	16
May 7, 1906....	66 (gluten bread).	13.04	CO_2 (gm.)..	51	9	10	14	6	....	....	....	....	204	39	19
H. C. K., 2 hrs...	706 (skim milk)...		O_2 (gm.)..	47	9	9	6	9	....	....	....	....	188	33	18
			Heat (cals.).	164	13	13	15	14	....	....	....	....	656	55	8
Plasmon and skim milk.															
May 4, 1906....	[2]376.....	15.07	CO_2 (gm.)..	47	14	15	9	8	....	....	....	....	188	46	24
H. R. D., 2 hrs...			O_2 (gm.)..	42	....	12	5	10	....	....	....	....	[3]126	[3]27	21
			Heat (cals.).	146	26	31	7	13	....	....	....	....	584	77	13
May 15, 1906...	[4]586.....	15.25	CO_2 (gm.)..	51	11	15	12	2	3	6	....	....	306	49	16
H. C. K., 2 hrs..			O_2 (gm.)..	47	12	0	11	3	−8	6	....	....	282	24	9
			Heat (cals.).	164	27	15	14	−4	16	−6	....	....	984	62	6

[1]Individual measurements of the oxygen consumption were not obtained in periods 2 and 3, but the total increment for the two periods (4 hours) was 11 grams. See table 224, p. 294.

[2]This includes 100 grams plasmon, 70 grams plasmon milk biscuit, and 206 grams skim milk.

[3]Total increase and total basal value for oxygen are for 6 hours; the oxygen was lost in first period.

[4]This includes 100 grams plasmon meal, 47 grams plasmon graham biscuit, and 439 grams skim milk.

there was an increment of 10 calories in the heat production, but the values for the carbon-dioxide production and the oxygen consumption both present slight negative values. An examination of the details of the experiment shows that positive increments occur in the first two periods, these amounts being counterbalanced by negative values in subsequent periods. In the first two experiments given in table 230 the food taken had practically the same nitrogen content and the experiments may therefore be considered as duplicates, although with different subjects; both indicate a considerable increase in all of the three factors. In the next two experiments, which were made with the same subjects, the food taken was approximately one-half that ingested in the preceding experiments; the increments found were proportionally smaller than those in the first two experiments. In both pairs of experiments, the values for A. W. W. are lower than those for A. H. M., especially for carbon-dioxide production and heat production. From these four experiments, therefore, one may infer that the influence of the ingestion of beefsteak is by no means the same with different individuals. The values for oxygen consumption for the two subjects are considerably at variance, as in the high-nitrogen experiments the increments are alike, while with the low-nitrogen intake the increment for A. H. M. was but half that with A. W. W., thus showing the difficulties in comparing results by direct and indirect calorimetry for experimental periods less than 24 hours.

In comparing the data for exiperiments such as these, we should expect to find that each gram of ncrement in carbon dioxide produced would correspond to an increment in heat production of $2\frac{1}{2}$ to 3 calories. An examination of the results in table 230 shows that this ratio holds true in but few instances. Thus, in the first four experiments the amount is more nearly 2 calories per gram of carbon dioxide than 3 calories; this is true, also, for many other experiments. In the experiment with V. G., January 21, 1911, we find that the ratio is 7 calories per gram of carbon dioxide, while in the following experiment it is only 1.2 calories, and in the two succeeding experiments the ratios are less than 1 calorie. Such irregularities as these discredit the use of direct calorimetry in short experiments. On the other hand, when the computations of indirect calorimetry are based upon carbon dioxide alone, they are open to the serious objection that the increase found may be due to change in the character of the katabolism or to a formation of fat from carbohydrate, but when the measurements are made by direct calorimetry it provides positive evidence that the increment in heat production is due to the food alone. The data for heat production in table 230 show that such an increment was found in every experiment in which protein food was ingested, although in some cases the increment was very small.

For a true comparison of the results of the different experiments, it is necessary to compare only those in which approximately the same amounts of nitrogen were ingested and with experimental periods of approximately the same length. In many instances the total effect of the food had by no means ceased at the end of the period of observation. In other experiments it was evident that the full effect of the food ingestion was obtained, inasmuch as increments of less than 0.5 gram, as well as negative values, were found in the later periods. It was hoped that some information might be obtained as to the relationship between the amount of nitrogen ingested and the increments in the metabolism. Generally speaking, the larger amounts of meat produced the larger increments. This may not hold true, however, when different individuals are used for subjects, as may be seen by a comparison of the experiment with A. W. W., April 6, 1907, in which 755 grams of meat were ingested, with that with J. R., December 4, 1908, in which 418 grams were taken. Although both of the experiments continued for 8 hours, the increment in heat production was slightly more in the second experiment than in the first, but the increment in oxygen consumption and carbon-dioxide production in the experiment with J. R. was about 70 per cent of that in the experiment with A. W. W. It will thus be seen that marked irregularities occur in all these experiments, and no constancy was found in comparisons with different individuals and rarely in comparisons for the same individual.

It was also hoped that some light could be obtained as to the influence of animal protein as compared with that of vegetable protein. A superficial examination of the data in table 230 shows no material difference in the two classes of proteins in their influence upon the metabolism, but here again the comparisons are complicated by the fact that the experiments are made with different individuals and with different experimental plans. With the purest protein substance used (glidine), the experiments in which the largest amount was given, *i. e.*, 9.70 grams of nitrogen, gave duplicate values for the same subject which were only reasonably satisfactory. Comparing these values with those obtained with beefsteak or with beefsteak combined with potato chips or bread, in which essentially the same amount of nitrogen was ingested, we find that the average values with glidine are slightly higher than those for beefsteak, although even with the same amount of nitrogen the values with beefsteak vary widely. The gluten bread experiments, while complicated by a relatively small amount of animal protein in the form of skim milk, show increments comparable with those obtained with beefsteak. One must conclude, therefore, that these experiments, defective though they are, indicate that there is no clearly defined difference between animal and vegetable proteins in their influence upon the metabolism.

The series of respiration experiments which are summarized in table 215 were made subsequent to most of the calorimeter experiments included in table 230 and were designed to throw more light upon the quantitative relationships. Varying amounts of beefsteak were taken in these experiments, although in none was so large an amount eaten as in the first two calorimeter experiments given in table 230. The heat production in the periods subsequent to the taking of the food invariably exceeded the basal value. Usually the experiments were not continued sufficiently long to include the total effect of the food, so that the basal value would again be reached; consequently the increases recorded in the last two columns of table 215 frequently represent incomplete increments. Most of the experiments did not extend over a period longer than 6 hours, although in one case the observations were continued over a period of nearly 12 hours. The irregularity in the effect upon different individuals of the ingestion of the same amount of nitrogen is strikingly shown in the percentage increase above the basal value, these figures being given in the last column of the table. While theoretically we should expect to find continually decreasing values for these percentages, as the experiments are arranged in the table in the order of decreasing amounts of beefsteak eaten, this is not actually the case.

Making due allowance for the fact that the time over which the experiments were continued varies somewhat, it is still clear that there is no uniform relationship between the amount of nitrogen ingested and the actual increase above the basal metabolism. Whether such a relationship could have been established if the experiments had been continued until the effect of food had completely ceased would appear, from the data obtained, extremely improbable. Experiments of this length are very tiresome for both subject and observer; nevertheless such experiments should ultimately be made. For the present, therefore, we can only reiterate the deductions made from the results of the calorimeter experiments to the effect that while the ingestion of protein in almost any amount invariably produces an increase over the basal metabolism which may be 25 per cent for several hours and for short periods may rise to 45 per cent (see tables 198 to 229), no definite mathematical relationship between the amount of protein ingested and the increment in the total metabolism can be noted from these values. It is probable that in any study of these results it should be remembered that these subjects were unlike in body-weight and in active mass of protoplasmic tissue.

INGESTION OF MIXED NUTRIENTS.

Studies with a single mixed nutrient were made with but one food material, this being whole milk. In addition, two experiments were made in which the milk was combined with one other food material, and in a considerable number of experiments the metabolism was measured after a diet such as would be taken in one or more ordinary meals.

MILK.

No other single food material contains the three important nutrients, protein, fat, and carbohydrate, in such relatively well-balanced proportions as whole milk does. Three calorimeter experiments and one respiration experiment were made to study the effect upon the metabolism of the ingestion of milk. Statistical data not included in the tables or in the discussion of the experiments are as follows:

H. R. D., 8^h40^m a. m. to 4^h40^m p. m., March 21, 1908. 59.2 kilograms.—During experiment sat very quietly, reading about four-fifths of time; very drowsy at 10 a. m. Urinated 6^h50^m a. m., 11^h40^m a. m., and 4^h55^m p. m.; defecated (after enema) about 7^h20^m a. m. Body-temperature: 36.95°, 36.69°, 36.71°, 36.71°, 36.69° C. Pulse rate, 63; respiration rate, 19.

A. L. L., 8^h40^m a. m. to 4^h40^m p. m., March 22, 1906. 68.3 kilograms.—Urinated 7^h20^m a. m. and 4^h57^m p. m. Sat very quietly reading; not sleepy except near end of experiment. Body-temperature: 36.72°, 36.65°, 36.70°, 36.64°, 36.53° C. Pulse rate, 61; respiration rate, 19.

A. H. M., 8^h30^m a. m. to 4^h30^m p. m., March 23, 1906. 67.0 kilograms.—Urinated 6^h30^m a. m., 12^h40^m p. m., 4^h45^m p. m. Read very little, and sat quiet in chair; drowsy, especially in afternoon. Body-temperature: 36.59°, 36.44°, 36.42°, 36.44°, 36.33° C. Pulse rate, 53; respiration rate, 16.

H. F. T., 10^h21^m a. m. to 2^h15^m p. m., July 14, 1911. 57.9 kilograms.—Milk experiment on this day preceded by observations of the gaseous exchange $8\frac{1}{2}$ hours after ingestion of beefsteak. (See page 286.) Tired and restless in fifth period. Nitrogen in urine per hour 7 a. m. to 10^h40^m a. m., 0.69 gram; 10^h40^m a. m. to 2^h20^m p. m., 0.72 gram.

CALORIMETER EXPERIMENTS.

In the calorimeter experiments with milk, a study was made of the influence of approximately 600 grams of whole milk, in which 19 per cent of the fuel value came from protein, 52 per cent from fat, and 29 per cent from carbohydrates. These experiments were carried out with three subjects on successive days with the Middletown respiration calorimeter. As was usual with these earlier experiments, the only basal values obtainable were determined several days or weeks before or after the food study and hence are not ideal for purposes of comparison. The observations were all made in 2-hour periods.

H. R. D., March 21, 1906.—The data obtained following the ingestion of 599 grams of milk and 9 grams of lime-water, with a fuel value of 444 calories, are given in table 231. These show an increment in carbon-dioxide production in all of the periods, with but 1 gram in the last period. The values for oxygen consumption were irregular, but

a positive increment for the total experiment was obtained of 4 grams. The greatest increment in heat production was in the first period, with variations above or below basal thereafter. The influence of this amount of milk upon the metabolism of the subject was therefore relatively slight. The urine was collected but once for the experiment, and showed an average excretion of 0.86 gram of nitrogen per 2 hours.

TABLE 231.—*H. R. D., March 21, 1906. Sitting.* (2-hour periods.)

Milk (whole):
Amount, 599 grams;[1] nitrogen, 3.17 grams; total energy, 471 cals.
Fuel value: Total, 444 cals.; from protein, 19 p. ct.; from fat, 52 p. ct.; from carbohydrates 29 p. ct.
Nitrogen in urine, 0.86 gram per 2 hours.[2]
Basal values (February 6 to April 20, 1906): CO_2, 47 grams; O_2, 42 grams; heat, 146 cals.

Time after food.	Carbon dioxide.		Oxygen.		Heat.	
	Total.	Increase.	Total.	Increase.	Total.	Increase.
	grams.	*grams.*	*grams.*	*grams.*	*cals.*	*cals.*
0 to 2 hours	50	3	40	−2	156	10
2 to 4 hours	51	4	43	1	146	0
4 to 6 hours	50	3	47	5	149	3
6 to 8 hours	48	1	42	0	144	−2
Total	199	11	172	4	595	11

[1]Also 9 grams lime-water.
[2]Sample included amount for about 1¾ hours without food preceding experiment.

A. L. L., March 22, 1906.—The details of the experiment are given in table 232. The subject drank 598 grams of milk, combined with 9 grams of lime-water, with a fuel value of 382 calories. In the experi-

TABLE 232.—*A. L. L., March 22, 1906. Sitting.* (2-hour periods.)

Milk (whole):
Amount, 598 grams;[1] nitrogen, 3.15 grams; total energy, 410 cals.
Fuel value: Total, 382 cals.; from protein, 19 p. ct.; from fat, 52 p. ct.; from carbohydrates, 29 p. ct.
Nitrogen in urine, 0.83 gram per 2 hours.[2]
Basal values (April 3 and 6, 1906): CO_2, 47 grams; O_2, 43 grams; heat, 145 cals.

Time after food.	Carbon dioxide.		Oxygen.		Heat.	
	Total.	Increase.	Total.	Increase.	Total.	Increase.
	grams.	*grams.*	*grams.*	*grams.*	*cals.*	*cals.*
0 to 2 hours	59	12	44	1	172	27
2 to 4 hours	54	7	45	2	166	21
4 to 6 hours	50	3	45	2	153	8
6 to 8 hours	45	−2	44	1	148	3
Total	208	20	178	6	639	59

[1]Also 9 grams lime-water.
[2]Sample included amount for about 1¼ hours without food preceding experiment.

mental period of 8 hours, the total increment for carbon-dioxide production was 20 grams, for oxygen consumption 6 grams, and for heat production 59 calories. The only basal values available were those determined 12 and 15 days subsequent to the food experiment. Nevertheless it is evident that the increment with this subject was materially greater than with the subject of the preceding experiment.

A. H. M., March 23, 1906.—Following the ingestion of 599 grams milk and 8 grams of lime-water, with a fuel value of 385 calories, an increment was obtained in the carbon-dioxide production in the first three periods, with a value below basal in the fourth period. (See table 233.) The oxygen consumption was somewhat irregular and also showed values below basal in the fourth period, with a total increment of 11 grams for the 8 hours. The heat production in the first three periods increased measurably, but here again a value below the base-line was obtained in the last period. It is significant that in the fourth period values below basal are observed for all of the three

TABLE 233.—*A. H. M., March 23, 1906. Sitting.* (2-hour periods.)

Milk (whole):
Amount, 599 grams;[1] nitrogen, 3.17 grams; total energy, 412 cals.
Fuel value: Total, 385 cals.; from protein, 19 p. ct.; from fat, 52 p. ct.; from carbohydrates, 29 p. ct.
Nitrogen in urine, 1.25 grams per 2 hours.[2]
Basal values (February 12 and 14, 1906): CO_2, 45 grams; O_2, 40 grams; heat, 142 cals.

Time after food.	Carbon dioxide.		Oxygen.		Heat.	
	Total.	Increase.	Total.	Increase.	Total.	Increase.
	grams.	*grams.*	*grams.*	*grams.*	*cals.*	*cals.*
0 to 2 hours	53	8	46	6	170	28
2 to 4 hours	51	6	90	10	157	15
4 to 6 hours	51	6			155	13
6 to 8 hours	41	−4	35	−5	137	−5
Total	196	16	171	11	619	51

[1]Also 8 grams lime-water.
[2]Sample included amount for about 2 hours without food preceding experiment.

factors of metabolism, strongly implying that the basal value determined on February 12 and 14, 1906, was erroneous and that a true basal value for this day would have been nearer to that found in this period of the experiment. In that case the increment due to the ingestion of milk would have been greater than here recorded. It is clear that even with this imperfect base-line there was a very measurable increment due to the ingestion of milk, especially in the first three periods. Since the total nitrogen intake was but 3.17 grams, it is probable that this effect upon the metabolism should not be ascribed solely to the protein in the milk. In our study of the effect of carbo-

hydrate ingestion, lactose, which is present in milk in considerable amounts, was noted as having a positive effect upon the metabolism; hence we probably have here a summation effect of the protein and lactose. While the three experiments as a whole are not especially satisfactory as duplicate experiments, they are uniform in indicating a positive increment due to the ingestion of milk.

RESPIRATION EXPERIMENT.

Only one respiration experiment was made with milk, this being a part of the later investigations in Boston. The universal respiration apparatus was employed, with experimental periods of the usual 15-minute length. The basal value was determined in several periods immediately preceding the taking of the food.

H. F. T., July 14, 1911.—The amount of milk taken by this subject was 500 grams, with a fuel value of 358 calories. This energy content was somewhat less than that of the milk used in the calorimeter experiments, although derived from the three nutrients in the same proportions as in those experiments. The details of the experiment are given in table 234. The maximum increase in metabolism, which occurred inside of the first hour, was relatively slight, the heat production rising from 0.91 to 1.01 calories per minute. The basal value was reached in 3 hours. Although unaccompanied by respiration experiments with other subjects or with the same subject, the results of this experiment are of interest for comparison with the data obtained in the calorimeter experiments with this common food material.

TABLE 234.—*H. F. T., July 14, 1911. Lying.* (Values per minute.)

Milk (whole):
Amount, 500 grams; nitrogen, 2.64 grams; total energy, 381 cals.
Fuel value, 358 cals.; from protein, 19 p. ct.; from fat, 52 p. ct.; from carbohydrates, 29 p. ct.

Time.	Average respiration rate.	Carbon dioxide.	Respiratory quotient.	Oxygen.	Average pulse rate.	Heat (computed).
Without food:[1]		*c.c.*		*c.c.*		*cals.*
Av. of 3 periods	10	151	0.80	189	44	0.91
With food:[2]						
10^h21^m a.m	10	153	.73	209	45	.99
10 57 a.m	10	177	.86	207	43	1.01
11 24 a.m	11	171	.83	205	45	.99
11 55 a.m	10	161	.83	195	44	.94
12 39 p.m	10	164	.86	191	..	.93
1 15 p.m	10	158	.82	193	43	.93
2 00 p.m	11	160	.84	191	43	.93

[1]Subject had eaten 206 grams beefsteak at 12 midnight, July 13.
[2]Subject drank milk between 10^h07^m and 10^h10^m a. m.

MIXED DIET.

While the study of specific food materials is of abstract physiological value, especially those containing but a single nutrient like the sugars in our study of the carbohydrates, nevertheless the most practical interest lies in the influence of a mixed diet upon the basal metabolism. We have for consideration in this connection the results of 15 experiments in which the metabolism was studied after a mixed diet. Of these, 13 were calorimeter experiments and 2 were respiration experiments. The composition of the diet used in these 15 experiments is given in table 235. Additional evidence as to the influence of a mixed diet upon the metabolism is also given in an abstract of four calorimeter experiments, previously published, which followed several days of fasting.

TABLE 235.—*Percentage composition of mixed diets used in experiments.*

Subject and date.	Protein.	Fat.	Carbohydrates.	Fuel value per gram.
	p. ct.	*p. ct.*	*p. ct.*	*cals.*
A. H. M..Feb. 2– 3, 1906.....	4.0[1]	4.5[1]	12.1[1]	1.087[1]
D. W.....Jan. 12–14, 1906.....	5.2	3.2	24.1	1.531
H. R. D..Dec. 7– 8, 1905.....	3.9	3.8	12.2	1.038
N. M. P..Dec. 11–12, 1905.....	4.8	4.7	19.7	1.448
H. L. H..June 14, 1910[2].....	4.2[1]	3.7[1]	22.5[1]	1.432[1]
A. L. L...Feb. 13, 1906[2].....	5.3[1]	11.7[1]	13.9[1]	1.873
A. L. L...Feb. 15, 1906[2].....	4.5[1]	9.8[1]	14.3[1]	1.640
A. H. M..Feb. 16, 1906.....	6.8[1]	14.4[1]	18.9[1]	2.461
A. H. M..Feb. 19, 1906.....	7.7[1]	14.0[1]	19.5[1]	2.410
H. R. D..Feb. 17, 1906[2].....	5.4[1]	8.7[1]	12.9[1]	1.641
H. R. D..Feb. 21, 1906[2].....	6.2[1]	12.0[1]	14.3[1]	2.017
A. L. L...Apr. 6– 7, 1906[2].....	4.4	10.8[1]	15.3[1]	1.815
H. R. D..Apr. 10–11, 1906.....	7.1	14.6[1]	12.9[1]	2.201
J. J. C....Feb. 28, 1911[3].....	2.9	3.0[1]	14.7[1]	1.003[1]
A. F.....Apr. 20, 1915.....	5.5[1]	7.6[1]	10.2[1]	1.360[1]

[1]Computed.

[2]Diet on this day also included sugar, for which the composition is, carbohydrate, 100 p. ct. and fuel value, 3.960 cals. per gram.

[3]For composition of black bread used in diet of this day, see table 50, page 124. Sugar in the diet is not included in the composition here given.

CALORIMETER EXPERIMENTS.

In our earlier investigations with the respiration calorimeter in Middletown practically all of the experiments following a 2-days' fasting experiment were with mixed diet. These have already been considered in a previous section of this report, in which the metabolism during fast and after food as measured in 24-hour periods was discussed.[1] It is desirable, however, to group them in abstract here with other calorimeter experiments with mixed diet not yet discussed. In two of the mixed-diet experiments, but two food materials were used, one of the

[1]See pp. 52 to 72.

experiments being with crackers and milk and the other with cereal and milk. In 8 experiments excessive amounts of food were taken, either as breakfast or supper. In all but one of the calorimeter experiments the measurements were made with the Middletown respiration calorimeter. The experiment with H. L. H. was made with the bed calorimeter in Boston. In the first four experiments discussed the determinations were made in 24-hour periods. The basal values in all cases were determined on some other than the experimental day.

A. H. M., February 2–3, 1906.—For the experiment with 70 grams soda crackers, 50 grams graham wafers, and 1,030 grams whole milk, a basal value was used which was obtained in November 1905. (See table 22, page 70). The fuel value of the diet was 1,250 calories, of which 15 per cent came from protein, 39 per cent from fat, and 46 per cent from carbohydrates. The ingestion of this food in three portions during the day resulted in an increment of 149 grams in carbon-dioxide production, 80 grams in oxygen consumption, and 239 calories in heat production. The doubtful expediency of employing a basal value so far removed from the values obtained in the food experiment has already been discussed in our previous consideration of these results and need not be further emphasized. The main point to be noted here is the fact that the crackers-and-milk diet resulted in an increment of approximately 14 per cent in the heat production.

D. W., January 12–14, 1906.—The subject took 166 grams of a dry cereal and 450 grams of whole milk each day in three portions. (See table 13, page 62). This diet had a fuel value of 943 calories, of which 14 per cent came from protein, 20 per cent from fat, and 66 per cent from carbohydrates. The basal value used was determined in a fasting experiment of two days preceding the food experiment. On the first food day there was only a slight increment over the basal average value, the metabolism being essentially the same as that on the last day of the fast. On the second day with food there was a considerable increment in the metabolism, which amounted for the heat production to 184 calories. Here again we must call attention to the previous discussion as to the errors involved in the used of a base-line of this character. It is clear, however, that the ingestion of the food arrested the fall in the metabolism incidental to fasting and finally produced a rise.

H. R. D., December 7–8, 1905.—The diet consisted of 125 grams orange juice, 1,427 grams milk, 181 grams of a dry cereal, 128 grams eggs, and 149 grams apples. This amount of food was taken in three portions at the ordinary meal times. (See table 11, page 61). The basal value used for comparison was determined in a 2-day fast immediately preceding the food day. The fuel value of the diet was 2,086 calories, of which 16 per cent came from protein, 35 per cent from fat, and 49 per cent from carbohydrates. The ingestion of this amount of

food resulted in a positive increase in metabolism, as shown by the total increment in the heat production of 189 calories, or approximately a 10 per cent increase.

N. M. P., December 11–12, 1905.—The food intake in this experiment (see table 12, page 61) was much larger than in that with H. R. D., the diet consisting of 260 grams orange juice, 97 grams dry cereal, 914 grams milk, 233 grams bread, 13 grams butter, 634 grams cocoa, 179 grams eggs, 362 grams beans, 184 grams bananas, and 222 grams crackers, a total amount of 3,098 grams, with a fuel value of 4,486 calories. Of this energy, 14 per cent came from protein, 30 per cent from fat, and 56 per cent from carbohydrates. As in the preceding experiment, the food was taken in three portions at the usual meal times. The increase in heat production as a result of taking this food was 379 calories, or approximately 17 per cent. The nitrogen excretion also increased considerably.

H. L. H., June 14, 1910.—The experiment with this subject differed considerably from the four previous experiments discussed in that it was but 5 hours long and the measurements were made with the bed calorimeter in Boston in 1-hour periods. The food, which was largely carbohydrates, was taken in one meal (supper) approximately 1¼ hours before the beginning of the measurements. It consisted of 226 grams rolls, 97 grams sugar cookies, 44 grams sugar, 296 grams strawberries, and 468 grams milk. The fuel value of this diet was 1,731 calories, of which 68 per cent came from carbohydrates, 21 per cent from fat, and 11 per cent from protein. The basal value used for comparison was determined on the following day in a series of quiet periods, which were alternated with restless periods to avoid the necessity of enforcing

TABLE 236.—*H. L. H., June 14, 1910. Lying.* (1-hour periods.)

Supper (mixed diet):

Amount, 1,131 grams; nitrogen, 7.31 grams; total energy, 1,794 cals.

Fuel value: Total, 1,731 cals.; from protein, 11 p. ct.; from fat, 21 p. ct.; from carbohydrates, 68 p. ct.

Nitrogen in urine, 0.34 gram per hour.

Basal values (June 15, 1910): CO_2, 25 grams; O_2, 22 grams; heat, 68 cals.

Time elapsed since subject finished eating.[1]	Carbon dioxide.		Oxygen.		Heat.	
	Total.	Increase.	Total.	Increase.	Total.	Increas.
	grams.	*grams.*	*grams.*	*grams.*	*cals.*	*cals.*
1¼ to 2¼ hours	34.5	9.5	25.0	3.0	83	15
2¼ to 3¼ hours	37.0	12.0	27.0	5.0	95	27
3¼ to 4¼ hours	30.5	5.5	25.5	3.5	92	24
4¼ to 5¼ hours	36.0	11.0	22.0	0.0	80	12
5¼ to 6¼ hours	25.5	0.5	19.0	−3.0	67	−1
Total	163.5	38.5	118.5	8.5	417	77

muscular rest for too long a time. This alternation is in accordance with the usage of Professor Johansson and was our first attempt to employ his method. The data for these quiet basal periods are given in table 237. The results obtained in the food experiment, which are given in table 236, show an increment in the carbon-dioxide production for practically $5\frac{1}{4}$ hours after the food was given. The oxygen consumption also showed an increase in the first three periods, while the heat production continued above the basal value in 4 periods. Basal values were obtained for all the factors of metabolism in the last period of the experiment.

TABLE 237.—*Basal metabolism of subject H. L. H., June 15, 1910, in bed calorimeter.*[1]
(1-hour periods.)

Period.	Carbon dioxide.	Oxygen.	Heat.
	grams.	*grams.*	*cals.*
8^h19^m a.m. to 9^h19^m a.m.	26.0	23.0	71
10 19 a.m. to 11 19 a.m.	25.0	22.0	68
12 19 p.m. to 1 19 p.m.	25.0	21.0	69
2 19 p.m. to 3 19 p.m.	26.0	22.5	64
4 19 p.m. to 6 19 p.m.	23.5	21.5	68
	23.5	21.5	68
Average	25.0	22.0	68

[1]Nitrogen in urine per hour 9^h40^m a. m. to 8^h25^m p. m., 0.38 gram.

HEAVY BREAKFAST.

During the third week of February 1906, the Middletown respiration calorimeter was employed for studying the increment in the metabolism due to the eating of a large amount of food. The meal selected for this purpose was breakfast, as it was believed that a subject could eat a larger amount at this time rather than at the end of the day, especially if his supper the night before had been light. Six experiments with three subjects were made on this plan; they were all 8 hours in length, with the measurements in 2-hour periods.

A. L. L., February 13, 1906.—The breakfast for this experiment consisted of 180 grams bread, 73 grams butter, 78 grams sugar, 311 grams oatmeal, 235 grams cream, 182 grams milk, 214 grams cocoa, and 92 grams eggs, a total amount of 1,365 grams. The fuel value of this food was 2,720 calories, 10 per cent of which came from protein, 52 per cent from fat, and 38 per cent from carbohydrates. The data for the experiment are given in table 238. The basal value used for comparison was drawn from three experiments within a week of the food experiment. The total increment was 61 grams in the carbon-dioxide production, 48 grams in the oxygen consumption, and 162

calories in the heat production. As the basal value for the heat production was approximately 600 calories for the 8 hours of the experiment, it will be seen that this increment of 162 calories corresponded to an increase in the metabolism of 27 per cent. There was no indication that the stimulus to the metabolism had ceased at the end of the experiment, as even in the last 2-hour period there was an increase of 7 grams in the carbon-dioxide production, 8 grams in the oxygen consumption, and 26 calories in the heat production. It is evident that this excessive amount of food, although not so large as it was hoped the subject could eat, produced a prolonged increase in the basal metabolism.

TABLE 238.—*A. L. L., February 13, 1906. Sitting.* (2-hour periods.)

Heavy breakfast (mixed diet):
Amount, 1,365 grams; nitrogen, 10.91 grams; total energy, 2,797 cals.
Fuel value: Total, 2,720 cals.; from protein, 10 p. ct.; from fat, 52 p. ct.; from carbohydrates, 38 p. ct.
Basal values (February 7 to 20, 1906): CO_2, 47 grams; O_2, 41 grams; heat, 151 cals.

Time after food.[1]	Carbon dioxide.		Oxygen.		Heat.	
	Total.	Increase.	Total.	Increase.	Total.	Increase.
	grams.	*grams.*	*grams.*	*grams.*	*cals.*	*cals.*
1½ to 3½ hours.....	74	27	60	19	201	50
3½ to 5½ hours.....	63	16	50	9	204	53
5½ to 7½ hours.....	58	11	53	12	184	33
7½ to 9½ hours.....	54	7	49	8	177	26
Total.....	249	61	212	48	766	162

[1]Subject ate food in about 30 minutes.

A. L. L., February 15, 1906.—Less food was taken in this experiment than in the experiment on February 13 with the same subject. The food eaten was 180 grams bread, 78 grams sugar, 323 grams oatmeal, 200 grams cream, 55 grams butter, 262 grams cocoa, and 98 grams eggs, a total of 1,196 grams. The fuel value of this diet was 2,142 calories, of which 9 per cent was derived from protein, 47 per cent from fat, and 44 per cent from carbohydrates. The results of the experiment are given in table 239. The carbon-dioxide increment continued for the entire experimental period, with a total increment of 49 grams. The oxygen consumption apparently reached its basal value in the third period, with a total increment for the experiment of 20 grams. The total increment in heat production was 96 calories, but the increase was but 5 calories in the last period. The total increase in heat production was approximately 16 per cent.

A. H. M., February 16, 1906.—The second subject used for this series of experiments was able to take much larger amounts of food than A. L. L. On this date he ate for his breakfast 72 grams potato chips, 148 grams peanut butter, 222 grams bananas, 319 grams oatmeal,

TABLE 239.—*A. L. L., February 15, 1906. Sitting.* (2-hour periods.)

Heavy breakfast (mixed diet):

Amount, 1,196 grams; nitrogen, 8 grams; total energy, 2,213 cals.

Fuel value: Total, 2,142 cals.; from protein, 9 p. ct.; from fat, 47 p. ct.; from carbohydrates, 44 p. ct.

Nitrogen in urine, 0.90 gram per 2 hours.

Basal values (February 7 to 20, 1906): CO_2, 47 grams; O_2, 41 grams; heat, 151 cals.

Time after food.[1]	Carbon dioxide.		Oxygen.		Heat.	
	Total.	Increase.	Total.	Increase.	Total.	Increase.
	grams.	*grams.*	*grams.*	*grams.*	*cals.*	*cals.*
1½ to 3½ hours.....	70	23	54	13	186	35
3½ to 5½ hours.....	63	16	48	7	186	35
5½ to 7½ hours.....	52	5	38	−3	172	21
7½ to 9½ hours.....	52	5	44	3	156	5
Total.....	237	49	184	20	700	96

[1]Subject ate food in 20 minutes.

103 grams graham bread, 25 grams cheese, 139 grams whole wheat breakfast food (dry), 99 grams eggs, and 652 grams cream, a total of 1,779 grams. The fuel value was 4,378 calories, of which 12 per cent came from protein, 56 per cent from fat, and 32 per cent from carbohydrates. The data for the experiment given in table 240 show a striking rise in the carbon-dioxide production, with similar increases in the oxygen consumption and heat production, all of which continued throughout the experiment, with no evidence of a return to basal value, even in the last period. The total increment was 82 grams in carbon-dioxide production, 65 grams in oxygen consumption, and 186 calories in heat production. As the basal value for heat production was 568

TABLE 240.—*A. H. M., February 16, 1906. Sitting.* (2-hour periods.)

Heavy breakfast (mixed diet):

Amount, 1,779 grams; nitrogen, 19.46 grams; total energy, 4,547 cals.

Fuel value: Total, 4,378 cals.; from protein, 12 p. ct.; from fat, 56 p. ct.; from carbohydrates, 32 p. ct.

Nitrogen in urine, 1.63 grams per 2 hours.

Basal values (February 12 and 14, 1906): CO_2, 45 grams; O_2, 40 grams; heat, 142 cals.

Time after food.[1]	Carbon dioxide.		Oxygen.		Heat.	
	Total.	Increase.	Total.	Increase.	Total.	Increase.
	grams.	*grams.*	*grams.*	*grams.*	*cals.*	*cals.*
1¾ to 3¾ hours.....	70	25	56	16	197	55
3¾ to 5¾ hours.....	67	22	58	18	197	55
5¾ to 7¾ hours.....	64	19	54	14	188	46
7¾ to 9¾ hours.....	61	16	57	17	172	30
Total.....	262	82	225	65	754	186

[1]Subject ate food in about 25 minutes.

calories for an 8-hour period, this increment of 186 calories shows a long and sustained increase, amounting to nearly 33 per cent of the basal metabolism. During the first two periods the increment was 55 calories above a basal value of 142 calories, or nearly 40 per cent increase.

A. H. M., February 19, 1906.—The diet in this experiment consisted of 204 grams bananas, 63 grams potato chips, 29 grams potted chicken, 139 grams whole wheat breakfast food (dry), 103 grams graham bread, 284 grams oatmeal, 520 grams cream, 141 grams eggs, 150 grams peanut butter, a total of 1,633 grams. The fuel value of the food was 3,936 calories, of which 13 per cent came from protein, 54 per cent from fat, and 33 per cent from carbohydrates. As a result of the ingestion of this food, there was a large increase in the three factors of metabolism which continued throughout the experiment. (See table 241.) In the first two periods the increments in the heat production of 64 and 65 calories, respectively, correspond to an increase above basal of approximately 45 per cent. Even in the last period the increment in the heat was 41 calories. It can easily be seen from these results that a meal of this type taken in the morning would have an effect upon the metabolism for practically the entire working day.

TABLE 241.—*A. H. M., February 19, 1906. Sitting.* (2-hour periods.)

Heavy breakfast (mixed diet):

Amount, 1,633 grams; nitrogen, 20.11 grams; total energy, 4,112 cals.

Fuel value: Total, 3,936 cals.; from protein, 13 p. ct.; from fat, 54 p. ct.; from carbohydrates, 33 p. ct.

Nitrogen in urine, 1.72 grams per 2 hours.

Basal values (February 12 and 14, 1906): CO_2, 45 grams; O_2, 40 grams; heat, 142 cals.

Time after food.[1]	Carbon dioxide.		Oxygen.		Heat.	
	Total.	Increase.	Total	Increase.	Total.	Increase.
	grams.	*grams.*	*grams.*	*grams.*	*cals.*	*cals.*
1½ to 3½ hours.....	73	28	66	26	206	64
3½ to 5½ hours.....	68	23	53	13	207	65
5½ to 7½ hours.....	66	21	55	15	201	59
7½ to 9½ hours.....	62	17	56	16	183	41
Total.....	269	89	230	70	797	229

[1]Subject ate food in 41 minutes.

H. R. D., February 17, 1906.—For breakfast this subject ate 77 grams dry cereal, 134 grams sugar, 381 grams cream, 123 grams apples, 658 grams milk, 205 grams baked beans, 31 grams bread, 29 grams peanut butter, 41 grams graham crackers, 146 grams eggs, and 3 grams potato chips, a total of 1,828 grams. This diet had a fuel value of 3,311 calories, of which 12 per cent came from protein, 43 per cent from fat, and 45 per cent from carbohydrates. The details of the experiment

are given in table 242. As a result of the ingestion of this food there was a marked increase in the three factors of metabolism which continued throughout the experiment; the increase in the heat production for the last period amounted to 33 calories. The total increase in heat production of 181 calories represents approximately a 32 per cent increment in this factor; similar percentage increments were noted for carbon-dioxide production and oxygen consumption.

TABLE 242.—*H. R. D., February 17, 1906. Sitting.* (2-hour periods.)

Heavy breakfast (mixed diet):
Amount, 1,828 grams; nitrogen, 14.64 grams; total energy, 3,439 cals.
Fuel value: Total, 3,311 cals.; from protein, 12 p. ct.; from fat, 43 p. ct.; from carbohydrates. 45 p. ct.
Nitrogen in urine, 1.25 grams per 2 hours.
Basal values (February 6 and 10, 1906): CO_2, 47 grams; O_2, 42 grams; heat, 143 cals.

Time after food.[1]	Carbon dioxide.		Oxygen.		Heat.	
	Total.	Increase.	Total.	Increase.	Total.	Increase.
	grams.	*grams.*	*grams.*	*grams.*	*cals.*	*cals.*
1½ to 3½ hours.....	69	22	58	16	196	53
3½ to 5½ hours.....	66	19	52	10	191	48
5½ to 7½ hours.....	59	12	51	9	190	47
7½ to 9½ hours.....	61	14	45	3	176	33
Total.....	255	67	206	38	753	181

[1]Subject ate food in 51 minutes.

H. R. D., February 21, 1906.—The experiment on this date was practically a duplicate of that with the same subject on February 17, as the diet had approximately the same fuel value. The proportions of energy from protein, fat, and carbohydrate were also approximately the same, although in this experiment a somewhat larger proportion of the energy was supplied by fat with correspondingly less from carbohydrates. The breakfast consisted of 81 grams graham crackers, 40 grams peanut butter, 26 grams cheese, 89 grams cereal, 56 grams sugar, 76 grams apples, 46 grams bread, 145 grams baked beans, 189 grams boiled eggs, 397 grams milk, and 634 grams cream, a total of 1,779 grams. The fuel value of the diet was 3,697 calories, of which 12 per cent came from protein, 54 per cent from fat, and 34 per cent from carbohydrates. The results of the experiment are given in table 243. Here again we find large increments in the metabolism throughout the experiment, with no evidence of a cessation at the end of the 8-hour experimental period. The total increase in heat production was not so large as in the experiment on February 17, being only 148 calories, or approximately 26 per cent of the basal value. The results show, however, like all of the experiments in this series, a prolonged stimulus to the metabolism which continued for the entire 8 or 9 hours following the ingestion of the food.

TABLE 243.—*H. R. D., February 21, 1906. Sitting.* (2-hour periods.)

Heavy breakfast (mixed diet):

Amount, 1,779 grams; nitrogen, 17.09 grams; total energy, 3,845 cals.

Fuel value: Total, 3,697 cals.; from protein, 12 p. ct.; from fat, 54 p. ct.; from carbohydrates, 34 p. ct.

Nitrogen in urine, 1.22 grams per 2 hours.

Basal values (February 6 and 10, 1906): CO_2, 47 grams; O_2, 42 grams; heat, 143 cals.

Time after food.[1]	Carbon dioxide.		Oxygen.		Heat.	
	Total.	Increase.	Total.	Increase.	Total.	Increase
	grams.	*grams.*	*grams.*	*grams.*	*cals.*	*cals.*
1¾ to 3¾ hours.....	63	16	56	14	188	45
3¾ to 5¾ hours.....	67	20	53	11	174	31
5¾ to 7¾ hours.....	61	14	54	12	182	39
7¾ to 9¾ hours.....	57	10	48	6	176	33
Total.....	248	60	211	43	720	148

[1]Subject ate food in about 45 minutes.

HEAVY SUPPER.

Two experiments were made with the Middletown calorimeter in which excessive amounts of food were taken as a supper. Otherwise the experiments were similar in plan to the heavy-breakfast experiments, except that the measurements continued for a somewhat longer time and were not made in 2-hour periods. Both of the subjects had been used in the heavy-breakfast experiments.

A. L. L., April 6–7, 1906.—The food taken consisted of 145 grams bread, 42 grams butter, 109 grams eggs, 57 grams potato chips, 256 grams bananas, 90 grams sweet chocolate, 446 grams milk, 103 grams cream, and 25 grams sugar, a total of 1,273 grams. The fuel value of the food was 2,364 calories, of which 10 per cent came from protein, 53 per cent from fat, and 37 per cent from carbohydrates.

The food experiment continued from 9^h15^m p. m., April 6, to 1^h15^m p. m., April 7, in all, a period of 16 hours. The experiment was divided into three periods. In the first period of 9 hours from 9^h15^m p. m., April 6, to 6^h15^m a. m., April 7, the subject lay quiet and asleep for the greater part of the time. In the first hour and a half there was considerable activity, as he weighed himself, received and ate the food, returned the dishes used to the food aperture, and prepared for bed. During this period of activity he went to the food aperture 3 times and opened it about 15 times, and wiped up some spilled cream. He ate his supper between 9^h40^m p. m. and 10^h34^m p. m. and retired at 10^h50^m p. m. In the second period of one hour between 6^h15^m a. m. and 7^h15^m a. m., April 7, the subject rose, weighed himself, and dressed, then sat quiet (reading) for the remainder of the time. The third period

of 6 hours continued from 7^h15^m a. m. to 1^h15^m p. m.; the subject was quiet throughout the whole period.

The basal values used for comparison were obtained on April 19 to 20, 1906, and on April 6, 1906. The lengths of the first and third periods of measurement do not correspond exactly to those of the food experiment, but the values have been computed to the same basis. The first fasting period contained less muscular activity than the corresponding food period, as the subject ate no food and retired 12 minutes after the beginning of the period.

An examination of the results given in table 244 shows that the heat production in the 16 hours of the food experiment increased 281 calories over that in 16 hours of fasting, representing a percentage increment of approximately 25 per cent. Furthermore, in the last 6 hours of the experiment there was a metabolism measurably above that of the control period, showing a prolonged after-effect of the food ingestion.

TABLE 244.—*A. L. L., April 6–7, 1906.*

Heavy supper (mixed diet):
Amount, 1,273 grams; nitrogen, 8.87 grams; total energy, 2,442 cals.
Fuel value: Total, 2,364 cals.; from protein, 10 p. ct.; from fat, 53 p. ct.; from carbohydrates, 37 p. ct.

Date.	Body position.	Period.	Nitrogen in urine.	Carbon dioxide.	Oxygen.	Heat.
1906.						
Without food:			*gms.*	*gms.*	*gms.*	*cals.*
Apr. 19–20..	Lying[1].....	9^h00^mp.m. to 7^h00^ma.m..	[2]1.66	[2]201	[2]173	[2]590
Apr. 20.....	Rising, weighing, sitting..	7 00 a.m. to 8 00 a.m..	.23	32	27	92
Apr. 6.....	Sitting.....	1 15 p.m. to 9 15 p.m..	[3]1.07	[3]135	[3]126	[3]426
		Total (16 hours)..	....	368	326	1,108
With food:						
Apr. 6–7....	Lying[1].....	9^h15^mp.m. to 6^h15^ma.m.[4]	3.27	271	245	792
Apr. 7.....	Rising, weighing, sitting..	6 15 a.m. to 7 15 a.m..	.46	37	28	116
Apr. 7.....	Sitting.....	7 15 a.m. to 1 15 p.m..	2.23	152	138	481
		Total (16 hours)..	....	460	411	1,389
		Increase.....	....	92	85	281

[1]Subject retired at 9^h12^m p. m. on night of April 19–20 and at 10^h50^m p. m. on April 6–7. Previous to these times there was the activity connected with weighing and the preparations for retiring; on the night of April 6–7 subject went to the food aperture 3 times and opened it about 15 times.
[2]Computed to basis of 9 hours, *i. e.*, to the duration of corresponding period with food.
[3]Computed to basis of 6 hours.
[4]Subject finished eating about 1½ hours after the beginning of this period.

H. R. D., April 10–11, 1906.—The food taken in this experiment was 37 grams dry cereal, 111 grams sweet chocolate, 95 grams peanut butter, 233 grams baked beans, 76 grams apples, 307 grams milk, 409 grams cream, 67 grams whole-wheat bread, and 229 grams boiled

eggs, a total of 1,564 grams. The fuel value of this diet was 3,442 calories, of which 13 per cent came from protein, 63 per cent from fat, and 24 per cent from carbohydrates. The measurements were made in one period of $10\frac{1}{4}$ hours and one period of 10 hours. (See table 245.) The average basal value used for the first food period was drawn from measurements made on three different days with reasonably concordant values. Although the periods of measurement differed slightly from those of the food experiment, the basal values have been computed to a comparable basis.

TABLE 245.—*H. R. D., April 10–11, 1906.*

Heavy supper (mixed diet):

Amount, 1,564 grams; nitrogen, 17.81 grams; total energy, 3,599 cals.

Fuel value: Total, 3,442 cals.; from protein, 13 p. ct.; from fat, 63 p. ct.; from carbohydrates, 24 p. ct.

Date.	Body position.	Period.	Nitrogen in urine.	Carbon dioxide.	Oxygen.	Heat.
1906.						
Without food:			*grams.*	*grams.*	*grams.*	*cals.*
Apr. 20–21..	Lying[1]...	9^h00^mp.m. to 7^h00^ma.m....	[2]4.95	[2]226	[2]208	[2]694
May 9–10..	Lying[1]...	9 30 p.m. to 7 30 a.m....	[2]5.82	[2]218	[2]188	[2]648
May 17–18..	Lying[1]...	9 10 p.m. to 7 10 a.m....	[2]7.68	[2]224	[2]187	[2]666
		Average.....	6.15	223	194	[3]669
Apr. 10.....	Sitting...	1^h00^mp.m. to 9^h00^mp.m....	[4]3.50	[4]240	[4]210	[4]755
		Total ($20\frac{1}{4}$ hours)...	....	463	404	1,424
With food:						
Apr. 10–11..	Lying[1]...	9^h00^mp.m. to 7^h15^ma.m.[5]...	6.85	325	293	921
Apr. 11.....	Sitting...	8 15 a.m.[6] to 6 15 p.m....	5.26	264	232	837
		Total ($20\frac{1}{4}$ hours)...	....	589	525	1,758
		Increase.....	....	126	121	334

[1]Subject retired at 9^h16^m p. m. on night of April 20–21, at 9^h42^m p. m. on May 9–10, at 9^h30^m p. m. on May 17–18, and at 10^h26^m p. m. on April 10–11. Previous to these times there was the activity connected with weighing and the preparation for retiring; on the night of April 10–11 subject went to the food aperture twice and opened it 20 times.

[2]Computed to basis of $10\frac{1}{4}$ hours, *i. e.*, to duration of corresponding period with food.

[3]Heat values on nights of April 20–21 and May 17–18 not corrected for small change in body-weight or for change in body-temperature.

[4]Computed to basis of 10 hours.

[5]Subject finished eating about an hour after the beginning of this period.

[6]Period, 7^h15^m a. m. to 8^h15^m a. m., when subject rose, weighed, etc., is omitted because satisfactory base-line was not obtained.

As in the previous experiment, the activity in the first food period was somewhat greater than that in the fasting periods with which it was compared, for the subject retired earlier in the fasting experiments and the activity due to receiving and eating food was absent. He went to bed on April 20 at 9^h16^m p. m., on May 9 at 9^h42^m p. m., and on May 17 at 9^h30^m p. m. On April 10–11 (the food period) he ate supper between 9^h20^m p. m. and 10^h08^m p. m., finishing about an hour after the beginning of the experiment. During this time he went to the food aperture twice and opened and shut it 20 times. He retired at 10^h26^m p. m. As no suitable basal value could be obtained for com-

parison, the active period in the morning from 7^h15^m a. m. to 8^h15^m a. m. has been omitted from the table.

As a result of eating this heavy supper a considerable increment was found for all of the factors of metabolism. That for heat production during the total period of $20\frac{1}{4}$ hours was 334 calories, this corresponding to a percentage increment of approximately 23 per cent. A comparison of the two sitting periods shows a prolonged after-effect of the heavy meal on the morning following its ingestion.

RESPIRATION EXPERIMENTS.

In the calorimeter experiments no attempt was made to apportion the increment from period to period and study the time relations to find if there were a "peak" effect. This was possible only with short-period experiments, such as could be made with a respiration apparatus. Unfortunately but two experiments with mixed diet were made with such an apparatus. In both of these experiments the basal value was determined in several periods just preceding the ingestion of the food.

J. J. C., February 28, 1911.—The universal respiration apparatus was used for this experiment of 12 periods (3 periods of fasting and 9 periods after food). The diet consisted of 210 grams black bread, 15 grams sugar, 25 grams butter, and 500 grams coffee, or a total amount of 750 grams. The fuel value of the diet was 796 calories, of which 11 per cent came from protein, 26 per cent from fat, and 63 per cent from carbohydrates. The results of the experiment are given in table 246. In about $1\frac{1}{2}$ hours after the taking of the food, the heat production had increased from 1.16 calories to a maximum of 1.43

TABLE 246.—*J. J. C., February 28, 1911. Lying.* (Values per minute.)

Mixed diet:

Amount, 750 grams;[1] nitrogen, 3.42 grams; total energy, 826 cals.

Fuel value: Total, 796 cals.; from protein, 11 p. ct.; from fat, 26 p. ct.; from carbohydrates, 63 p. ct.

Time.	Average respiration rate.	Carbon dioxide.	Respiratory quotient.	Oxygen.	Average pulse rate.	Heat (computed).
		c.c.		*c.c.*		*cals.*
Without food:						
Av. of 3 periods	16	198	0.83	239	69	1.16
With food:[2]						
11^h05^m a.m.	16	210	....	...	73	1.18
11 41 a.m.	16	248	.90	275	69	1.35
12 14 p.m.	17	257	.88	291	72	1.43
12 44 p.m.	17	246	.87	284	73	1.39
1 17 p.m.	18	251	.92	274	72	1.36
1 48 p.m.	16	248	.95	262	72	1.31
2 23 p.m.	16	243	....	...	68	1.33
2 59 p.m.	15	221	.84	264	66	1.28
3 31 p.m.	15	214	.87	246	64	1.20

[1]Includes 500 grams coffee. [2]Subject ate between 10^h40^m and 10^h54^m a. m.

calories per minute. At the end of the experiment, nearly 5 hours after the ingestion of food, the heat production had not quite reached the basal value.

A. F., April 20, 1915.—The second respiration experiment with a mixed diet was made with the Tissot respiration apparatus. The food included 45 grams egg (boiled), 250 grams milk, 37 grams toast, and 12 grams butter, a total of 344 grams. The fuel value of the diet was 468 calories, of which 17 per cent came from protein, 52 per cent from fat, and 31 per cent from carbohydrate. The details of the experiment are given in table 247. The heat production increased from a basal value of 1.27 calories per minute to a maximum of 1.45 calories per minute in approximately 30 minutes after the taking of the food. This was followed by a gradual decrease, but at the end of the experiments nearly $3\frac{1}{2}$ hours after the food had been taken, the basal value had not, been reached.

TABLE 247.—*A. F., April 20, 1915. Lying.* (Values per minute.)

Mixed diet:

Amount, 344 grams; nitrogen, 3.04 grams; total energy, 494 cals.

Fuel value: Total, 468 cals.; from protein, 17 p. ct.; from fat, 52 p. ct.; from carbohydrates, 31 p. ct.

Time.	Ventilation (reduced).	Average respiration rate.	Carbon dioxide.	Respiratory quotient.	Oxygen.	Average pulse rate.	Heat.
Without food:	*liters.*		*c.c.*		*c.c.*		*cals.*
Av. of 2 periods..	8.12	31.3	210	0.79	265	70	1.27
With food:[1]							
9^h58^m a.m.....	9.09	34.9	240	.80	301	..	1.45
10 16 a.m.....	9.15	35.2	235	.81	292	67	1.41
11 27 a.m.[2].....	9.33	37.0	231	.81	286	62	1.38
11 48 a.m.....	6.53	17.1	217	.80	270	60	1.30
12 46 p.m.[2].....	6.33	16.6	216	.79	275	58	1.32

[1]Subject ate between 9^h23^m and 9^h29^m a. m.

[2]Subject sat up between 10^h28^m and 10^h58^m a. m. and between 12^h and 12^h25^m p. m.

It is evident that these two respiration experiments throw but little light upon the general course of the metabolism after the taking of a mixed diet. The calorimeter experiments, especially those following an excessive amount of food, showed a pronounced effect upon the metabolism. It is much to be regretted that the experimental procedure of the studies with the calorimeter did not permit the careful separation of the results into short periods, so that we might gain some information as to the exact course of the metabolism, the time relations, and the altitude of the peak effect. While we are able to study more closely these particular points in the short-period respiration experiments with carbohydrate and protein diets, the evidence supplied with mixed diets is slight, suggesting only that the peak effect probably occurred soon after the ingestion of the food.

PREVIOUSLY PUBLISHED EXPERIMENTS WITH MIXED DIETS.

In an earlier publication on fasting,[1] four food experiments with mixed diets were reported following fasts of 4 to 7 days in duration. These have already been discussed in our consideration of the basal metabolism (see pages 55 to 60), but are abstracted here, as they give further information regarding the influence of a mixed diet. As stated in the previous discussion, our earlier plan was to use fasting values as base-lines, and then note the increment in the metabolism due to subsequent food ingestion. When we attempted to select a base-line, a number of serious objections to this at once presented themselves. In the first place it was noted that the total metabolism for the day almost invariably decreased gradually as the fast progressed. An examination of the data in table 248, which presents in abstract the four food experiments referred to, together with the preceding fasting periods, shows that in practically every instance there was a tendency for the heat production to decrease as the fasting continued. This tendency is most clearly shown in the fasting periods with S. A. B. on January 8

TABLE 248.—*Heat production of A. L. L. and S. A. B. without food and after the ingestion of a mixed diet.* [Values per 24-hours (7 a. m. to 7 a. m.)]

Subject and date.	Experimental day and fuel value of food.	Heat.	Subject and date.	Experimental day and fuel value of food.	Heat.
A. L. L.[2]			*S. A. B.*[3]		
1904.	*Fast.*	*cals.*	1905.	*Fast.*	*cals.*
Dec. 16–17	First	1,951	Jan. 8– 9	Second[4]	1,844
Dec. 17–18	Second	2,163	Jan. 9–10	Third	1,746
Dec. 18–19	Third	2,035	Jan. 10–11	Fourth	1,606
Dec. 19–20	Fourth	1,958		*Food.* (1,698 cals.)	
	Food. (2,502 cals.)		Jan. 11–12	First	1,677
Dec. 20–21	First	2,104			
Dec. 21–22	Second	2,223			
Dec. 22–23	Third	2,457			
S. A. B.[5]			*S. A. B.*[6]		
1905.	*Fast.*	*cals.*	1905.	*Fast.*	*cals.*
Jan. 28–29	First	1,866	Mar. 4– 5	First	1,765
Jan. 29–30	Second	1,791	Mar. 5– 6	Second	1,768
Jan. 30–31	Third	1,739	Mar. 6– 7	Third	1,797
Jan. 31–Feb. 1	Fourth	1,663	Mar. 7– 8	Fourth	1,775
Feb. 1– 2	Fifth	1,548	Mar. 8– 9	Fifth	1,649
	Food. (2,078 cals.)		Mar. 9–10	Sixth	1,553
Feb. 2–3	First	1,691	Mar. 10–11	Seventh	1,568
Feb. 3–4	Second	1,585		*Food.* (1,788 cals.)	
Feb. 4–5	Third	1,607	Mar. 11–12	First	1,767
			Mar. 12–13	Second	1,728
			Mar. 13–14	Third	1,754

[1]Benedict, Carnegie Inst. Wash. Pub. No. 77, 1907. [2]See table 7, p. 56.
[3]See table 8, p. 57. [4]First day not included because of work done on bicycle ergometer.
[5]See table 9, p. 58. [6]See table 10, p. 59.

to 11, 1905, and January 28 to February 2, 1905. It so happens that in the long fasting experiment of 7 days with S. A. B., the metabolism was essentially constant on the first 4 days; on the fifth day there was a sudden fall of over 100 calories, followed by another fall of 100 calories on the sixth day. In the experiment with A. L. L., the variations in the metabolism are somewhat pronounced; as a matter of fact the value is the same on the fourth day as on the first. Certain variations in these values from day to day may be in part accounted for by variations in muscular activity, although the attempt was made to have like activity on all days.

In the food experiment with A. L. L., the diet averaged 1,615 grams of a modified milk and 6 grams of plasmon per day, the total daily intake being 1,621 grams. This had a total fuel value of 2,502 calories, of which 9 per cent came from protein, 79 per cent from fat, and 12 per cent from carbohydrates. In the food experiment with S. A. B., January 11 to 12, 1905, the food taken per day was 1,253 grams of a modified milk and 106 grams of orange juice, the daily amount being 1,359 grams. The total fuel value was 1,698 calories, of which 9 per cent came from protein, 73 per cent from fat, and 18 per cent from carbohydrates. In the second food experiment with S. A. B. (February 2–5, 1905), the subject ate per day, 1,200 grams modified milk, 123 grams apples, 313 grams orange juice, and 35 grams graham crackers; the daily total was 1,671 grams. The total fuel value was 2,078 calories, of which 8 per cent came from protein, 65 per cent from fat, and 27 per cent from carbohydrates. In the last food experiment with S. A. B. (March 11–14, 1905), the food taken per day was 650 grams modified milk, 123 grams apples, 178 grams whole wheat breakfast food (dry), 10 grams gluten bread, and 313 grams orange juice, a daily total of 1,274 grams. The total fuel value was 1,788 calories, of which 9 per cent came from protein, 37 per cent from fat, and 54 per cent from carbohydrates.

The amounts of food ingested were unfortunately not satisfactory, the fuel value of the food intake being determined solely by the appetite of the subject on the first day of food following the fast. The diet for the subsequent days was the same as that on the first day, the amounts varying only a few grams, if at all. The fuel value of the food in the experiment with A. L. L. was considerably above the 24-hour maintenance requirement. In the first experiment with S. A. B., it was essentially that of maintenance, in the second experiment with this subject it was measurably above maintenance, and in the third experiment it was above the maintenance requirements during the fasting, but practically the same as the need for maintenance during the food period.

We thus consider here an influence of food upon the fasting metabolism which is not represented simply by the increment above a basal

value obtained by averaging all of the fasting days, as the basal value may change and in certain circumstances does change considerably during the fast. This was shown clearly in the fasting experiment of 31 days carried out in the Nutrition Laboratory.[1]

It hardly seems justifiable to attempt a computation of the fasting values obtained in these four experiments on the basis of per kilogram of body-weight or per square meter of body-surface. There were, to be sure, measurable losses in weight which were probably largely due to a loss of water from the body, especially in the earlier part of the fast. That there was a considerable loss in body-surface or of active heat-producing organized tissue is hardly conceivable. After the ingestion of food there were undoubtedly slight gains and losses in weight, but this discussion considers the organism as a whole, for only days with and without food are compared and no attempt is made to compare results obtained with different individuals.

Even in the first experiment recorded in table 248 (that with A. L. L.) the actual value of the base-line may be seriously questioned. An average value for the fasting periods would be not far from 2,025 calories. On this basis it can be seen that the ingestion of food, with a fuel value of 2,502 calories, barely increases the metabolism on the first day, increases it noticeably on the second, and produces a very pronounced increase on the third.

In the first experiment with S. A. B., the ingestion of food, with a fuel value essentially that of maintenance during fasting, resulted in a slight increase in the metabolism on the first food day over the metabolism on the fourth fasting day. If, however, the average of the fasting days is taken as an absolute value, it will be seen that the ingestion of food simply checked the progressive decrease in the metabolism. Here again the uncertainty of the base-line is noticeable.

In the second experiment with S. A. B., the ingestion of food with a fuel value considerably above the 24-hour maintenance requirement (over 500 calories above the final fasting-level) resulted in an increase in heat production of a little over 100 calories, while in the last experiment with S. A. B. the ingestion of food with a fuel value about 200 calories higher than the heat production on the sixth and seventh fasting days resulted in an increase in the metabolism of approximately 200 calories, the daily metabolism on the food days being almost exactly equal to the fuel value of the intake.[2]

From this varied picture of the influence of food ingestion upon metabolism following fasting, certain rather clear conclusions may be drawn. First, in all instances food produced an increased metabolism

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[1] Benedict, Carnegie Inst. Wash. Pub. No. 203, 1915, p. 372.

[2] Grafe (Deutsch. Arch. f. klin. Med., 1913–14, **113**, p. 1), comparing results obtained in a prolonged fast with those obtained with a diet of almost pure carbohydrates, found no rise in the metabolism after food.

over the last fasting day. This increase was independent of whether the fuel value of the food was considerably above or below that required for maintenance on the fasting day. Second, with the same individual the reaction to food was apparently by no means constant, for in the first two experiments with S. A. B. there was little, if any, increment due to food, although in the second experiment the fuel value of the food was from 400 to 500 calories above fasting maintenance requirements. On the contrary, at the end of the 7-day fast, food with a fuel value of 200 calories greater than the heat production of the last fasting day produced an increase of 200 calories in the total heat production. In all probability the length of the fast, the influence upon the basal metabolism of the fasting *per se*, the fuel value of the intake, and the proportion of protein in the intake are in some way related. In all of the experiments reported in this table there was an actual loss of nitrogen during the food experiment, as there was not sufficient protein in the intake to compensate for the outgo.

Finally, although the evidence is somewhat meager, it is of fundamental importance to consider the relationship between the ingestion of food and the basal metabolism after fasting, with a view to considering the possibilities of lowering the basal metabolism by inanition or undernutrition, and then maintaining the metabolic level on smaller food requirements than those ordinarily obtaining. For example, in the first experiment with S. A. B., we have a heat production on the second fasting day of 1,844 calories. On the fourth day this was reduced to 1,606 calories. The fuel value of the food ingested was 1,698 calories, which was essentially that required for maintenance. It is quite clear, therefore, that we deal here with a maintenance, at least temporarily obtaining, at a level of 150 or more calories below that on the second fasting day. The fact that in the second experiment with S. A. B. the 2,078 calories in the food did not cause a pronounced rise in the metabolism is likewise of great significance, for by 5 days of fasting the basal metabolism was lowered over 300 calories, and the ingestion of an excess amount of food over requirements on the next 3 days increased the heat production only about 100 calories above the last fasting day. On the other hand, these conclusions are considerably weakened by the course of the metabolism in the last experiment with S. A. B., in which food with a fuel value a little above the fasting requirements produced an increment of 200 calories, raising the metabolism to that on the first three or four fasting days.

These experiments are extremely suggestive in their bearing on the question of a basal metabolism lowered either by fasting or by prolonged undernutrition. They should be followed by observations on the influence of very moderate or barely maintenance diets to note if the tendency of the basal metabolism is to return to the initial value or to maintain the lowered value found as a result of undernutrition or

inanition. The reported experience of Germany and Austria at the time of writing would seem to indicate that observations of this kind are unwittingly being made there, but unfortunately it is probable that these are without a scientific measurement of the basal metabolism.[1] The statistical and superficial evidence indicates that certain classes of the Teutonic nations are subsisting on very low diets, so far as the calorie intake is concerned. While definite information is lacking as to their capacity to perform physical work on this low diet, the evidence of scientists who have visited Europe is somewhat conclusive in leading to the belief that there has been no proportionate loss in physical prowess or ability to perform work by this reduction in basal requirements. It is evident that this should be made the subject of most careful physiological research,[2] as apparently during fasting the organism becomes accustomed to existing upon a perceptibly lower level. There is naturally a loss of weight which is, it is true, in some small part made up of organized protoplasmic tissue and in large part of water and fatty tissue, but it is hardly conceivable that the heat-producing organism as such is proportionately reduced in capacity or size by the fasting. It is probable, however, that the stimulus to cellular activity is considerably lowered as a specific result of the fasting process. To what extent this stimulus is regenerated by moderate amounts of food, and how much the total metabolism may be influenced by the introduction of foreign protein, even under conditions when there is a draft upon body protein, are at present unsolved problems which should be carefully studied.

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[1]Since writing the above we have been able to secure a copy of an article by Loewy and Zuntz (Berlin. klin. Wochenschr., 1916, **53,** p. 825) and find that studies of the basal metabolism of both authors have been made with all the accuracy and painstaking care characteristic of Professor Zuntz's work. A pronounced decrease in basal metabolism as a result of the enforced reduction in diet is noted in both cases.

[2]Such a research has but recently (February 3, 1918) been completed by the Nutrition Laboratory and the data are now being elaborated for publication.

SOME RELATIONSHIPS BETWEEN ENERGY OUTPUT AND FOOD INTAKE.

The evidence presented in the foregoing chapters of this book deals principally with the energy transformations incidental to the ingestion of food. The experimental plan, while undergoing many changes in the decade in which the research has been in progress, nevertheless had, as its fundamental basis, a quantitative measurement of the energy transformations, either directly by means of the calorimeter or indirectly by calculation from data obtained for the respiratory exchange; in many of the experiments the nitrogen excretion was also determined. In several series of experiments a measurement was made of the increase in the energy output required for the mastication of food or the drinking of such liquids as water, coffee, and beef tea, but aside from the experiments in which the effect of mastication was studied, and a few calorimeter experiments in which the food materials were taken within the experimental period, the work of prehension and the external muscular work of eating were entirely excluded.

When possible, pure nutrients were used; if this was not practicable, as was only too frequently the case, a diet was employed in which a special nutrient predominated; thus a study could be made of the quantitative transformations following the ingestion of various kinds of food. It has been our plan to discuss in the foregoing chapters the experiments of each division of the research and thus in a way subsequent discussion is more or less of a repetition. It is perfectly legitimate, however, to recapitulate and attempt to correlate the findings for the several classes of food materials.

The only purely mechanical process studied was that of chewing. Although unfortunately the evidence is not definite in every case, nevertheless the general picture is sufficiently clear to state positively that mastication produces a distinct increase in the heat production. It has likewise been pointed out that, though contrary to the belief of some enthusiasts who advocate prolonged mastication for the more perfect digestion and assimilation of food material, the unused portion of modern food materials is, under normal conditions, extraordinarily small. The preliminary preparation of practically all of the food materials of civilized man removes in large part the indigestible portion; the energy content of almost any mixed diet may therefore be said to be absorbed to the extent of 90 per cent or over. Since pure carbohydrates are almost perfectly absorbed, it is probably safe to assume that with ordinary mixed diet approximately 95 per cent of the energy is actually absorbed.

The error in computing unabsorbed material from an analysis of the feces should again be emphasized. Fecal matter by no means consists wholly of undigested food material, but is made up in large part of

bacteria, the residue of digestive juices, and the débris of the epithelial lining of the intestinal tract. It is the common custom to analyze fecal material and to consider the nitrogen obtained as a measure of the unabsorbed protein, the fat as unabsorbed fat, and the carbohydrate, although existing in small amounts, as unabsorbed carbohydrates. This is fundamentally wrong, although the method for determining the digestibility of food has been based upon these false premises practically ever since the introduction of food analysis. It can be seen that an absorption of 95 per cent on this basis would, when properly interpreted, mean an actual energy absorption of nearly 98 per cent; hence the advocates of excessive mastication must attempt to increase an absorption which is already 98 per cent of the total amount. This is obviously impossible and physiologically unsound. If we further consider the extra energy required for excessive mastication, it is more than probable that such slight increase in absorption as may possibly occur with an excessive comminution of food materials by prolonged chewing may be considerably more than offset by the additional consumption of energy required for mastication.

In the experiments on drinking liquids, such as water which is without nutritive qualities, beef tea which has a measurable amount of the stimulating extractives (creatine and allied compounds), and coffee which contains a slight amount of extractives and of caffein (a heart stimulant), the picture is again not uniformly clear. Sufficient experimental evidence has been accumulated, however, to state positively that the drinking of large amounts of water results in an actual increase in the total production. Beef tea, taken either hot or cold, likewise slightly increases the metabolism. Coffee produces a similar slight increment. While a logical explanation of the increase in metabolism due to coffee and beef tea might be found in their content of stimulating materials, such as caffein and creatine, it is difficult to explain the increase due to water on this basis, and it is not impossible, even in the absence of positive evidence, that we have to deal here with an internal mechanical process which may be directly associated with the secretion of the normally occurring large amounts of urine following excessive liquid ingestion.

In a final consideration of the results of drinking liquids which show, as a rule, a relatively small increase in metabolism due to this factor, we must again state that the experimental technique was by no means perfect at that period of the research, and that the defects in the baseline frequently vitiated many of the results. As was clearly brought out in the discussion of the basal metabolism, such variations have considerable significance when the basal values are used for comparison with values obtained in subsequent periods in which only small increments are found; it is thus especially important to secure accurate basal values for such experiments. Accordingly, in studying the

results of the group of experiments under consideration, it is necessary to draw conclusions not from the detailed results, which were based in some cases upon defective values, but from the general picture presented. This general picture shows that the ingestion of a large amount of liquid, such as water, coffee, or beef tea, is followed by a measurable increase in the metabolism.

Following the ingestion of food materials a pronounced increment in the metabolism was almost invariably found. We may therefore disregard possible inaccuracies in the base-line and discuss the experiments on the general assumption that the basal values were determined with sufficient accuracy to warrant quantitative deductions from the increments actually measured, although we freely admit that whenever practicable a carefully determined base-line each day prior to the ingestion of food is highly desirable, if not, indeed, absolutely essential.

The observed increment in the metabolism as a result of the ingestion of food is in accordance with the experience of nearly all of the other investigators in this field. The increase was especially pronounced with protein, carbohydrates, and mixed diets, and less pronounced when diets with a preponderance of fat were used.

GENERAL QUANTITATIVE RELATIONS.

The fact that different amounts of the several foodstuffs produce varying increases in metabolism would make it appear that the establishment of definite mathematical relationships between the amounts of food ingested, the character of the food ingested, and the increments would be relatively simple. This, however, on close analysis, proves to be far from the case.

To establish a quantitative relationship between the various foods ingested and the increase in the basal metabolism it is necessary to note first the length of the experimental period to be considered. If the total increment due to the ingestion of food is desired, the period of measurement must be extended until the increment due to the ingestion of food has disappeared and the metabolism has again reached the basal level. For instance, if the basal heat production is 70 calories per hour and the metabolism increases after the ingestion of food to 100 calories per hour for one or two hours, obviously no complete mathematical relationship can be established unless the measurements are continued until the basal value of 70 calories per hour is again obtained. This is somewhat difficult, especially when the stimulus effect is prolonged, as it is with protein.

The first quantitative relationship to be considered is the increment in the metabolism above the basal level, to find how far it is possible to increase the basal metabolism by the ingestion of nutrients. This is in reality a measurement of the absolute maximum increment due to the ingestion of food, somewhat similar to the "peak" effect in the load of a

power plant, and has considerable interest as an index of the possible maximum influence of food. With carbohydrates the basal metabolism may be increased to an average maximum of approximately 25 per cent by the ingestion of 100 grams of any one of several sugars. This increment occurs inside of two hours and the metabolism has a tendency to return to the base-line somewhat rapidly thereafter. For a detailed discussion of the differences in effect of various forms of sugars, the section on carbohydrates should be consulted. (See page 171.) Of special significance is the fact that the increment with levulose over that with either sucrose or dextrose, which was earlier reported from this laboratory,[1] is not noted when the results of all the experiments are combined, and we find that there is a greater similarity between levulose and dextrose than was at first believed. It will be seen, from table 173, that the levulose has a more pronounced effect upon carbon-dioxide production than the dextrose has, although not so great as that of sucrose. When the comparison is made on the basis of the heat production, it is found that the difference between dextrose and levulose in large part disappears, although sucrose still shows a higher value.

Most of the pure sugars were studied with both 75-gram and 100-gram portions. While no uniform variation was noted in the effect upon the metabolism, it was usually found that the increment with the larger amount was greater than with the smaller amount, although the differences were by no means proportional.

With protein the large increments in metabolism found by all workers were also noted in this research. The heat production increased usually to a maximum above the basal level of approximately 25 per cent, with a possible maximum of 45 per cent. (See tables 215 and 230.) The increment persisted for a long time, often from 8 to 12 hours. Indeed, our experiments were defective in that the experimental periods were in general not sufficiently extended to obtain the entire effect due to the protein ingestion. This prolonged increment is in striking contrast to the increments obtained with carbohydrates, which, while fairly high (25 per cent), nevertheless fell rapidly to a basal value after a relatively few hours.

The experiments with fat are of special interest, though unfortunately the most liable to criticism on the grounds of experimental error and faulty technique. The inherent difficulties in feeding American subjects large quantities of pure oil or pure fat made it impossible for us to carry out any experiments with pure oil, as did Gigon, and we were obliged to confine ourselves to experiments with cream and with butter and potato chips. In practically all of the combinations used, a certain amount of other nutrients was inevitably included, which somewhat complicated the deductions drawn from the experiments. The

[1]Benedict, Trans. 15th Int. Cong. Hygiene and Demography, Washington, 1913, 2 (2), p. 394.

evidence is, however, sufficiently extensive and the general trend is such as to justify the conclusion that the ingestion of a diet containing a preponderance of fat has a distinct effect upon the metabolism, although this was much less than that found with either protein or carbohydrate. The findings are so irregular that it is probably unjustifiable to use the single highest maximum value found, and we must therefore resort to the average figure, which is not far from a maximum of 12 per cent.

In the experiments with mixed diets, in which frequently the subject took a sufficient number of calories in one meal to provide maintenance for a man at severe muscular work the entire day, *i. e.*, approximately 4,000 calories, the maximum increment reached 40 per cent or more.

An absolute accuracy of ±3 per cent in the measurement of the basal metabolism on any given day is hardly obtainable. Furthermore, variations in the body position have an effect upon the basal metabolism. It has been shown that the basal value obtained with the subject lying quietly without food in the stomach may be increased slightly by having the subject sit upright in a chair.[1] On the other hand, Du Bois[2] finds that with the subject sitting properly supported in a steamer chair, the basal metabolism is not increased over that found with the subject in the lying position and in certain instances it was even decreased. Standing upright has been found to increase the metabolism approximately 10 per cent.[3]

The maximum effects obtained with carbohydrates, protein, and mixed diets are, however, very considerably greater than those due to ordinary changes of position. While one might state tentatively that the increments with food, at least at the height of digestion, are such as would be expected when man is performing light muscular work, the inadequate definition of the term "light muscular work" is such as to make this of little significance. Too little knowledge is available at present regarding the increments in metabolism accompanying simple, every-day customs; hence we find ourselves at a loss to compare the increments for these food materials with those accompanying minor muscular activity.

The increments with food are certainly much less than those obtained as a result of walking. On the other hand, since there is an increase in both the respiration and the circulation, it is evident that the ingestion of food and its effect upon metabolism are to be considered much more broadly than as an increment in the gaseous metabolism. There is unquestionably a stimulation in the muscular activity and general muscular tonus, accompanied by a sense of increased vigor, which is wholly out of proportion to the relatively small increase in the metab-

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[1]Emmes and Riche, Am. Journ. Physiol., 1911, **27**, p. 406.
[2]Soderstrom, Meyer, and E. F. Du Bois, Arch. Intern. Med., 1916, **17**, p. 872.
[3]Benedict and Murschhauser, Carnegie Inst. Wash. Pub. No. 231, 1915. Benedict and Carpenter, Carnegie Inst. Wash. Pub. No. 126, 1910.

olism. The increments are, however, sufficiently large to preclude any attempt to measure the basal metabolism during the active stages of digestion. Experimenters have therefore for years wisely insisted upon the post-absorptive condition, that is, 12 hours after the last meal. This is particularly necessary when the preceding diet has contained liberal quantities of protein or an excessive amount of a mixed diet. Our observations, in common with those of many others, show very clearly that the effect of the ingestion of pure carbohydrate or of fat is with normal individuals concluded in a relatively few hours; were it not for the protein in the diet, therefore, one might state that the post-absorptive condition, or the so-called *nüchtern* condition, could be obtained in a much shorter period than 12 hours. Insistence on the 12-hour period is, in all events, the wiser course. Even with this interval, the injunction should be given to all subjects that excessive protein should not be taken in the last meal prior to the experimental period. (See page 286.)

RELATIONSHIP OF THE FUEL VALUE OF INGESTED FOOD TO EXCESS HEAT PRODUCTION.

A relationship of unusual interest is that of the increase in the heat production following the ingestion of food to that of the fuel value of the food taken. While it may seem at first sight a gross misuse of engineering terms or terms of efficiency to apply them to the apportionment of the caloric value of the ingested food of man, one might consider from an engineering standpoint or from that of industrial efficiency that the ingestion of food containing a certain number of calories would result in a certain amount of excess heat. Excess heat production represents an expenditure, either necessitated by the ingestion of food or resulting from the ingestion of food, and hence may logically be attributed to and in a sense chargeable to it.

In considering the metabolism subsequent to the ingestion of food, one should bear in mind the following facts: A considerable portion of the diet, at least with ruminants, is distinctly indigestible, this portion consisting of woody fiber, cellulose, etc. Secondly, only part of the protein of the diet is oxidized inside the body. This is true of all animal life, the unoxidized portion of the protein molecule being with mammals excreted chiefly in the form of urea. Furthermore, and this applies more particularly to ruminants, fermentation processes take place in the large intestine and cause a considerable production of marsh gas and a liberation of heat as the result of bacterial action. Finally, the ingestion of food *per se* causes an increase in the heat production. It is clear, therefore, that a measure of the heat of combustion of the intake has but little significance in relation to the ultimate

disposition of the total calories ingested or to the amount available or useful to the body.

Writers and experimenters in animal physiology, particularly in animal nutrition, have considered the energy of intake under various heads, and attempted its apportionment in some measure to the several processes of digestion and absorption. It has long been assumed that an increment in the heat production which is not directly available for muscular work is of little, if any, value to the animal economy. Writers have therefore been inclined to consider more especially that portion of the food intake which participates in the heat produced inside the body by muscular and glandular activity in distinction from the food taking part in the production of heat in fermentative activities. Such attempts to separate the various subdivisions of the energy consumption produce great confusion. Perhaps no one has given this phase of the matter more comprehensive treatment than Armsby in his admirable treatise.[1] He considers as metabolizable energy that fraction of the energy of the food which can enter into the metabolism of energy in the body, without differentiating as to the use made by the body of the energy thus metabolized. As the food of man contains but little unoxidizable material, like cellulose or fiber, the human diet may be considered as practically all digestible with the exception of the nitrogenous portion of the protein molecule which is excreted unoxidized in the form of urea. This material is still capable of being converted into heat, for each gram of urea has an energy value of 2.528 calories.[2] In computing the caloric value of the food intake, therefore, due allowance must be made for the unoxidizable material in the protein.

A consideration of the heat production of the human body deals chiefly with the disposition of the energy liberated after the food is absorbed. For convenience, we may consider that the ingestion of a definite amount of food produces an increase in the metabolism which may be chargeable to the food itself. If this is expressed in terms of calories, the total caloric value of the intake of food may properly be compared with that of the excess heat production. In this publication we have used for this purpose not the heat of combustion of the diet, but the so-called "fuel value," *i. e.*, the heat of combustion less the unoxidized portion of the protein.

In calculating the fuel values for the diets used in this research, two methods were employed. If the heat of combustion had not been determined, the energy derived from the protein, fat, and carbohydrate, respectively, was computed by means of the standard factors of Rubner,[3] the factor 4.1 being used for multiplying the grams of both the protein and the carbohydrate, and the factor 9.3 for multiplying the

[1]Armsby, The principles of animal nutrition, 2d ed., 1906.
[2]Emery and Benedict, Am. Journ. Physiol., 1911, **28**, p. 301.
[3]Rubner, Zeitschr. f. Biol., 1885, **21**, p. 377.

grams of fat in the diet. The sum of the calories found represented the total fuel value of the food.

If, however, the heat of combustion of the diet had been determined, another method was followed. Since the heat of combustion of protein is 5.5 calories per gram, the difference between 4.1 (the Rubner factor used for calculating the energy derived from protein) and 5.5, namely, 1.4, corresponds to the potential energy of the unoxidized portion of the protein molecule. With carbohydrates and fat the fuel value and the heat of combustion are essentially alike, although at times investigators have made slight allowances for the so-called "digestibility" of fat. Such correction of the values for fat is, however, a questionable procedure, and thus in calculating the fuel value from the heat of combustion we need only make correction for the unoxidized protein. The loss of energy from the unoxidized protein was found by multiplying the protein in 1 gram of the food by 1.4 (the potential energy of the unoxidized portion of the protein molecule); the resulting value deducted from the heat of combustion represented the fuel value of the diet per gram. (See table 50, page 124.) The fuel value of the total intake of food was then found by multiplying the grams of food ingested by the fuel value per gram.

If we compare the fuel value of the diet with the subsequent increase in the heat production, we obtain a mathematical relationship which may properly be designated as the "cost of digestion." This designation is in harmony with a convenient phraseology for similar relationships which is finding increased usage in all economic and many industrial processes and is beginning to be used by physiologists.[1]

For a true measure of the cost of digestion, it is necessary to have an accurate measure of the total heat production. We may not therefore content ourselves, as is too frequently done, with the simple measurement of the maximum or peak effect of the food ingested, but it is absolutely necessary to continue the measurements until the basal values are again reached and the total increment in the heat which is chargeable to the ingestion of the particular diet studied has been obtained for the entire period of measurement. Unfortunately, in a considerable number of our observations the experimental period was not continued a sufficient length of time to insure the return of the metabolism to the basal value and hence in the large majority of cases our measurement of the cost of digestion is a low rather than a maximum value. This should be taken into consideration in any estimate of our values for the cost of digestion.

The data regarding the cost of digestion in the studies made of the various nutrients and diets have been collected and tabulated.

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[1]See MacDonald, Proc. Roy. Soc. (B), 1915–17, 89, p. 394.

TABLE 249.—*Cost of digestion of various food materials, calorimeter experiments.*

Food material, subject, and date.	Total amount of food.	Hours after food to end of experiment.		Duration of experiment.	Period of increment observed in experiment.[1]	Fuel value.	Total increment observed.	Cost of digestion.
CARBOHYDRATES.								
Sucrose.	*grams.*	*hr.*	*min.*	*hours.*	*hours.*	*cals.*	*cals.*	*p. ct.*
A. H. M...Apr. 1, 1907..	191	8	15	8	6?	756	68	9
F. M. M..Jan. 31, 1910..	[2]100	4	48	5	3	[2]408	19	5
F. M. M..Feb. 2, 1910..	[2]100	4	0	4	3	[2]408	16	4
A. W. W..May 28, 1907..	80	4	15	4	2	317	6	2
Maltrose-dextrose mixture.								
Dr. R.....Feb. 21, 1907..	458	8	15	8	8	1,382	74	5
E. H. B...May 14, 1907..	431	8	0	8	6	1,301	39	3
A. H. M...Mar. 28, 1907..	307	8	30	8	8	927	94	10
A. L. L...May 13, 1907..	299	8	15	8	4?	902	40	4
J. J. C...Mar. 4, 1910..	[2]145	3	43	4	3	[2]449	41	9
Bananas and sugar.								
H. R. D...Mar. 31, 1906..	[3]1,276	8	0	8	6	1,562	107	7
H. R. D...Apr. 21, 1906..	[3]1,274	10	15	10	10	1,561	137	9
A. H. M...Apr. 2, 1906..	[3]1,207	8	0	8	8	1,448	94	6
A. L. L...Apr. 19, 1906..	[3]862	12	15	12	6	1,147	72	6
A. L. L...Mar. 30, 1906..	[3]864	8	0	8	4	1,109	88	8
J. J. C....Apr. 7, 1909..	[3]725	3	32	4	4	962	69	7
F. M. M..Apr. 8, 1909..	[3]620	2	30	3	3	655	19	3
Bananas.								
Dr. H.....Feb. 14, 1910..	403	2	38	3	3	409	27	7
F. M. M..Feb. 8, 1910..	400	3	43	4	1	406	−2	0
Dr. H.....Feb. 17, 1910..	397	3	41	4	3	403	21	5
Popcorn.								
A. H. M...Apr. 10, 1907..	199	8	45	8	8	847	66	8
H. B. W...Apr. 9, 1907..	187	9	0	8	8	796	39	5
Rice (boiled).								
A. L. L...May 27, 1907..	652	8	30	8	4?	432	7	2
FAT.								
Cream.								
J. J. C....Mar. 22, 1910..	445	3	49	4	..	1,362	−20	−1
D. J. M...June 7, 1910..	376	3	49	4	..	1,245	−2	0
D. J. M...June 3, 1910..	398	2	45	3	3	1,060	20	2
H. R. D...Mar. 28, 1906..	399	8	0	8	8	860	18	2
A. H. M...Apr. 5, 1906..	345	8	0	8	4	766	73	10
A. L. L...Mar. 27, 1906..	341	8	0	8	6	735	57	8
D. J. M...Mar. 23, 1910..	221	1	39	2	..	666	1	0
Butter and potato chips.								
A. H. M...Mar. 25, 1907..	[4]454	8	15	8	8	3,202	125	4
E. H. B...Mar. 19, 1907..	[4]316	7	15	6	6	1,924	57	3
L. E. E...Mar. 14, 1910..	[4]206	4	40	5	..	1,512	36	2
A. H. M...May 15, 1907..	[4]218	8	15	8	4	1,503	28	2
A. W. W..Apr. 25, 1907..	[4]189	9	0	8	4	1,276	15	1
J. R.....Mar. 21, 1910..	[4]187	4	43	5	5	1,266	11	1
J. J. C....Mar. 12, 1910..	[4]129	4	38	5	3	791	14	2
PROTEIN.								
Beefsteak.								
A. H. M...Apr. 5, 1907..	777	9	0	8	8	1,305	136	10
A. W. W..Apr. 6, 1907..	755	9	0	8	8	1,268	92	7
A. W. W..May 25, 1907..	373	8	15	8	6	981	45	5
A. H. M...May 24, 1907..	384	8	15	8	6	644	70	11
J. R.....Dec. 4, 1908..	418	9	30	8	8	603	104	17
F. M. M..Dec. 10, 1908..	217	9	15	8	3	364	24	7
F. M. M..Dec. 23, 1908..	208	7	0	6	5	349	17	5
L. E. E...Jan. 17, 1910..	163	7	30	5	5	245	47	19
F. M. M..Jan. 20, 1910..	132	7	0	5⅔	2	221	10	5

TABLE 249 (continued).—*Cost of digestion of various food materials, calorimeter experiments.*

Food material, subject, and date.	Total amount of food.	Hours after food to end of experiment.		Duration of experiment.	Period of increment observed in experiment.[1]	Fuel values.	Total increment observed.	Cost of digestion.
PROTEIN—cont.								
Beefsteak and bread.	*grams.*	*hrs.*	*min.*	*hours.*	*hours.*	*cals.*	*cals.*	*p. ct.*
F. M. M..Jan. 11, 1910..	[5]296	7	15	5	5	480	44	9
F. M. M..Jan. 12, 1910..	[5]237	6	0	5	2?	415	32	8
F. M. M..Jan. 14, 1910..	[5]225	6	15	5	5	399	46	12
Beefsteak and potato chips.								
J. J. C....May 11, 1911..	[6]311	10	0	6	4½	676	43	6
A. G. E...Jan. 23, 1911..	[6]292	3	45	3	3	566	12	2
V. G.....Jan. 21, 1911..	[6]235	4	0	3	3	463	21	5
C. H. H...Jan. 18, 1911..	[6]233	3	30	3	3	460	15	3
J. C. C....Jan. 17, 1911..	[6]213	3	30	3	3	425	28	7
Glidine.								
J. R.....May 10, 1910..	[7]70	4	15	4	4	[7]267	40	15
J. R.....May 5, 1910..	70	4	30	4	4	262	51	19
J. J. C....May 9, 1910..	45	5	0	4	4	168	38	23
L. E. E...May 3, 1910..	45	4	30	4	4	168	13	8
L. E. E...May 11, 1910..	45	3	30	3	3?	168	5	3
Gluten and skim milk.								
H. R. D...May 17, 1906..	[8]652	12	0	12	12	809	143	18
H. C. K...May 7, 1906..	[8]772	8	0	8	8	558	55	10
H. R. D...May 2, 1906..	[8]321	8	0	8	8	496	51	10
H. R. D...May 9, 1906..	[8]320	12	0	12	10	487	76	16
Plasmon and skim milk.								
H. R. D...May 4, 1906..	[9]376	8	0	8	8	758	77	10
H. C. K...May 15, 1906..	[9]586	12	15	12	10?	728	62	9
MIXED NUTRIENTS.								
Milk.								
H. R. D...Mar. 21, 1906..	608	8	0	8	6	444	11	2
A. H. M...Mar. 23, 1906..	607	8	0	8	6	385	51	13
A. L. L....Mar. 22, 1906..	607	8	0	8	6	382	59	15
Supper.								
H. L. H...June 14, 1910..	1,131	6	15	5	4	1,731	77	4
Heavy breakfast.								
A. H. M...Feb. 16, 1906..	1,779	9	45	8	8	4,378	186	4
A. H. M...Feb. 19, 1906..	1,633	9	30	8	8	3,936	229	6
H. R. D...Feb. 21, 1906..	1,779	9	45	8	8	3,697	148	4
H. R. D...Feb. 17, 1906..	1,828	9	30	8	8	3,311	181	5
A. L. L...Feb. 13, 1906..	1,365	9	30	8	8	2,720	162	6
A. L. L...Feb. 15, 1906..	1,196	9	30	8	8	2,142	96	4
Heavy supper.								
H. R. D...Apr. 10-11, 1906	1,664	19	15	20¼	19¼	3,442	334	10
A. L. L...Apr. 6- 7, 1906	1,273	14	30	16	14½	2,364	281	12

[1]These periods represent in each case the portion of the experiment in which increment of heat occurred as confirmed by increase in either or both of the other factors of metabolism. In experiments where no estimate is given, either the period of increment was not clearly defined or the amount of increment was actually negative.

[2]Also juice of one lemon; additional energy (11.5 cals.) included in fuel value.

[3]Amounts include sugar as follows: H. R. D., 103 grams each day; A. H. M., 86 grams; A. L. L., 99 grams each day; J. J. C., 77 grams; F. M. M., 9 grams.

[4]Amounts include potato chips as follows: A. H. M., March 25, 1907, 211 grams; May 15, 1907, 105 grams; E. H. B., 233 grams; L. E. E., 114 grams; A. W. W., 104 grams; J. R., 92 grams; J. J. C., 91 grams.

[5]Amounts include bread as follows: January 11, 50 grams; January 12, 38 grams; January 14, 24 grams.

[6]Amounts include 20 grams potato chips, except for J. J. C., May 11, 1911, 41 grams.

[7]Also juice of one-half lemon; additional energy (5.6 cals.) included in fuel value.

[8]Amounts include gluten as follows: H. R. D., May 17, 1906, 153 grams; May 2 and 9, 1906, 100 grams each day; H. C. K., 66 grams.

[9]Amounts include plasmon products as follows: H. R. D., 170 grams; H. C. K., 147 grams.

Inasmuch as a considerable number of the calorimeter experiments continued for 8 or more hours and hence represent a fairly long period of time when the metabolism was measured, and, indeed, usually a much longer period than that represented by the respiration experiments, the data for the two classes of experiments are given separately, those for the calorimeter experiments being included in table 249 and those for the respiration experiments in table 250. We have, furthermore,

TABLE 250.—*Cost of digestion of various food materials, respiration experiments.*

Food material, subject, and date.	Amount of food.	Period of observation.[1]		Fuel value.	Total increment observed.[1]	Cost of digestion.
CARBOHYDRATES.						
Dextrose.	*grams.*	*hrs.*	*min.*	*cals.*	*cals.*	*p. ct.*
K. H. A.....May 14, 1912.....	[2]100	4	7	[2]385	12	3
P. F. J.....May 15, 1912.....	[2]100	3	55	[2]385	6	2
Dr. P. R.....May 3, 1912.....	[2]100	4	29	[2]385	19	5
J. C. C.....Dec. 31, 1912.....	[3]100	3	21	[3]380	12	3
J. J. C.....Mar. 7, 1911.....	[3]100	3	57	[3]380	35	9
L. E. E.....May 29, 1911.....	[3]100	3	53	[3]380	18	5
C. H. H.....May 1, 1911.....	[3]100	6	6	[3]380	24	6
H. L. H.....May 24, 1911.....	[3]100	3	41	[3]380	17	4
B. M. K.....Dec. 30, 1912.....	100	5	0	374	21	6
A. J. O.....Dec. 11, 1914.....	100	1	27	374	14	4
J. J. C.....Dec. 28, 1910.....	[2]75	2	50	[2]292	8	3
V. G.....Dec. 29, 1910.....	[2]75	2	49	[2]292	15	5
J. J. C.....Dec. 22, 1910.....	[3]75	1	43	[3]286	13	5
V. G.....Dec. 23, 1910.....	[3]75	3	59	[3]286	19	7
Levulose.						
K. H. A.....May 18, 1912.....	[2]100	3	38	[2]384	20	5
P. F. J.....May 22, 1912.....	[2]100	3	58	[2]384	20	5
J. P. C.....Apr. 3, 1911.....	[3]100	5	24	[3]379	36	9
L. E. E.....May 22, 1911.....	[3]100	3	51	[3]379	21	6
C. H. H.....May 16, 1911.....	[3]100	5	35	[3]379	34	9
H. L. H.....June 1, 1911.....	[3]100	5	13	[3]379	24	6
A. J. O.....Dec. 8, 1914.....	100	1	29	373	12	3
J. J. C.....Jan. 4, 1911.....	[2]75	1	15	[2]291	10	3
J. J. C.....Dec. 31, 1910.....	75	6	47	280	38	14
Sucrose.						
Prof. C.....Nov. 20, 1909.....	[4]100	1	4	[4]422	15	4
Prof. C.....Nov. 22, 1909.....	[4]100	1	42	[4]422	16	4
H. H. A.....Jan. 2, 1912.....	[2]100	3	44	[2]408	36	9
L. E. E.....May 15, 1911.....	[3]100	2	34	[3]402	24	6
A. F. G.....May 20, 1911.....	[3]100	3	52	[3]402	30	7
C. H. H.....May 10, 1911.....	[3]100	3	3	[3]402	28	7
H. L. H.....May 17, 1911.....	[3]100	3	7	[3]402	23	6
A. J. O.....Dec. 29, 1914.....	100	1	30	396	26	7
J. J. C.....Dec. 6, 1910.....	[2]75	5	39	[2]309	27	9
J. J. C.....Dec. 8, 1910.....	[2]75	2	3	[2]309	11	4
J. J. C.....Dec. 20, 1910.....	[2]75	2	52	[2]309	16	5
V. G.....Nov. 18, 1910.....	[2]75	1	34	[2]309	9	3
V. G.....Nov. 30, 1910.....	[2]75	3	54	[2]309	21	7
J. J. C.....Nov. 22, 1910.....	[3]75	1	11	[3]303	10	3
V. G.....Nov. 21, 1910.....	[3]73	2	36	[3]295	12	4
Lactose.						
K. H. A.....May 23, 1912.....	[2]100	3	12	[2]385	10	3
L. E. E.....June 5, 1911.....	[5]100	4	5	[5]381	22	6
C. H. H.....May 23, 1911.....	[3]100	4	30	[3]379	22	6
H. L. H.....June 7, 1911.....	[3]100	3	38	[3]379	18	5
A. J. O.....Jan. 4, 1915.....	100	1	32	374	19	5

TABLE 250—*Cost of digestion of various food materials, respiration experiments.*—(Continude).

Food material, subject, and date.	Amount of food.	Period of observation.[1]		Fuel value.	Total increment observed.[1]	Cost of digestion.
PROTEIN.						
Beefsteak.	*grams.*	*hrs.*	*mins.*	*cals.*	*cals.*	*p. ct.*
J. J. C.....Apr. 25, 1911.....	[6]377	5	16	[6]790	81	10
H. L. H.....May 20, 1914.....	317	1	58	532	13	3
H. L. H.....July 1, 1911.....	249	11	42	418	138	33
H. G. E.....Dec. 12, 1914.....	200	2	51	336	25	7
J. F. M.....Apr. 23, 1914.....	198	2	19	332	19	6
J. K. M.....Nov. 26, 1912.....	196	3	3	329	28	9
J. J. C.....Nov. 3, 1910.....	150	4	8	314	51	16
D. M.....Oct. 28, 1911.....	[7]182	5	11	[7]305	86	28
Dr. S.....June 30, 1911.....	177	6	35	298	56	19
A. J. O.....Nov. 17, 1914.....	173	2	44	290	17	6
V. G.....Nov. 4, 1910.....	150	2	39	281	24	9
V. G.....Nov. 7, 1910.....	150	4	19	245	38	16
J. J. C.....Nov. 8, 1910.....	150	3	12	234	13	6
MIXED NUTRIENTS.						
Milk (whole).						
H. F. T.....July 14, 1911.....	500	4	5	358	11	3
Mixed diet.						
J. J. C.....Feb. 28, 1911.....	750	4	52	796	45	6
A. F.....Apr. 20, 1915.....	344	3	27	468	19	4

[1]From the time when subject finished eating to the end of the last observation, except in cases when the increment of heat ended earlier. For details and method of computation, see tables 126 to 168, 215, 234, 246, and 247; also pp. 151 and 152.

[2]Also juice of one lemon; additional energy (11.5 cals.) included in fuel value.

[3]Also juice of one-half lemon; additional energy (5.6 cals.) included in fuel value.

[4]Also 200 grams coffee; additional energy (26 cals.) included in fuel value.

[5]Also juice of two-thirds lemon; additional energy (7.6 cals.) included in fuel value.

[6]Includes 15 grams potato chips.

[7]Also a little butter; not included in amount or fuel value.

subdivided the experiments according to the preponderance of carbohydrate, protein, or fat in the several diets. The experiments in each group have been arranged according to the fuel value of the food intake. The data given in table 249 for the calorimeter experiments will be considered first.

To indicate when the effect of the ingestion of food ceased, the duration of the increment has been included in table 249. Frequently the basal metabolism was not reached before the experiment ended; under these conditions the value given is doubtless too low, for it is impossible to assume that the period of increment was coincident with the length of the experiment. In many instances, however, the duration of increment was considerably shorter than the total experimental period. This was true in the calorimeter experiments with sucrose, the only pure carbohydrate studied with the calorimeter.

It may be noted that a number of 24-hour experiments with mixed diet have been omitted from this table. While the basal value was determined during a complete fast, it seems necessary to recognize the

fact that the subsequent ingestion of food is made under conditions materially different from those of the procedure followed in practically all our experiments, since after a 24-hour fast the stimulating action of the food must first counteract the depressing effect of fasting. Experiments made under these conditions are hardly comparable with those made after only 12 hours without food, and the experiments with a basal value of 24 hours or more of fasting have not been included in the table.

The fuel values for the diet are at times extraordinarily high. Thus, in the experiment of February 16, 1906, the subject consumed a breakfast of mixed diet having an actual fuel value of approximately 4,400 calories. In several other instances the fuel value was over 3,300 calories. In general, however, it was not far from 500 to 1,200 calories.

The total increments, also given in table 249, varied from minus values (which are obviously due to faulty technique, defects in the determination of the basal value, or undue activity in the basal period) to the increment of 334 calories noted in a heavy supper experiment. Of special significance is the relationship between the total increments and the fuel values of the food intake, *i. e.*, the cost of digestion. The highest noted is that of 23 per cent for an experiment with J. J. C. on May 9, 1910, with glidine. Values above 10 per cent appear chiefly in the protein experiments, thus emphasizing strongly the fact that the ingestion of protein causes not only an actual maximum increase in metabolism higher than values obtained with the other nutrients, but a greater proportional increase when compared to the fuel value of the intake. Striking irregularities may be noted, and even with protein we find values under 10 per cent as frequently as above 10 per cent.

With bananas and sugar the cost of digestion is relatively high in practically all instances, averaging about 7 per cent. In the one experiment in which it is low, namely, 3 per cent with F. M. M. on April 8, 1909, there was an ingestion of but 9 grams of sugar. It is possible that the low increment of 19 calories noted on that date in a 3-hour observation may have been due to the fact that the superimposed effect of the cane sugar included in the diet on the other days was here absent. On the other hand, on the days when bananas alone were eaten, the two experiments with Dr. H. showed a cost of digestion of 5 and 7 per cent. Still another experiment made with F. M. M. showed no change.

While averaging results as diversified as those recorded in this table may appear to be a questionable procedure, yet we may tentatively state that the cost of digestion, or the relationship between the fuel value of the intake and the increase in the heat production due to the ingestion of food is, with carbohydrates, not far from 6 per cent on the average. With fat, aside from the two high values found with cream in the experiments with the subjects A. L. L. and A. H. M. in the spring of 1906, a small cost of digestion is noted, the average being not far from 2 per cent. With protein, although wide differences are found, the

values ranging from 2 to 23 per cent, the average value is approximately 10 per cent.

The three experiments with milk on March 21, 22, and 23 were planned to be comparable as the same amount of milk was given the subjects; the fuel value ranged from 382 to 444 calories. The increments obtained are somewhat irregular. A minimum of 11 calories was found with H. R. D. on the first day and fairly comparable values of 59 and 51 calories, respectively, were obtained on the two succeeding days. The fuel value of the milk taken in the last two experiments was practically the same. We see no reason for omitting the experiment on the first day, and hence the three experiments represent an average cost of digestion of milk of approximately 10 per cent.

In the previous comparisons, the fuel value did not exceed approximately 1,900 calories, except in one experiment with butter and potato chips, in which the intake of energy was 3,202 calories. In a group of experiments with an excess amount of food, characterized as "heavy-breakfast" experiments, the fuel value ranged from 2,142 to 4,378 calories. The cost of digestion in these experiments was fairly uniform, ranging from 4 to 6 per cent, with an average of 5 per cent. There were also two experiments of much longer duration than any of the other experiments included in this table, viz, those with H. R. D., April 10–11, and A. L. L., April 6–7, in which "heavy suppers" were taken with high fuel values. The cost of digestion was 10 and 12 per cent respectively. These higher figures may be due to faulty basal values or unusual activity in the food experiment, or the experiments may have been long enough to obtain all the increment which actually took place. They do not lend themselves, however, to very critical analysis.

Under ordinary conditions the normal individual rarely eats a meal containing a pure nutrient or a meal in which there is an excessive proportion of any single nutrient, but usually a fairly balanced combination of nutrients. It is accordingly of considerable practical significance that the six experiments with a heavy breakfast show such uniform percentages. While the use of average figures for the several groups of carbohydrates, fats, and proteins may be somewhat questionable, with mixed diets we may fairly state that the excess heat production as a result of ingesting such a diet is 5 per cent of the fuel value of the intake. In all of the heavy-breakfast experiments, the basal metabolism was not reached during the experimental period; the value of 5 per cent is therefore probably somewhat low and a value of 6 per cent would be more nearly in accord with the actual facts. We suggest, therefore, that as a general factor a heat production equivalent to 6 per cent of the fuel value may be expected as the result of the ingestion of a mixed diet.

The respiration experiments, summarized in table 250, were primarily designed to study the maximum effect rather than the total increment, and were therefore shorter than the calorimeter experiments. With the exception of one experiment with a mixed diet and one with beefsteak and potato chips, the fuel value of the diet did not exceed 600 calories, this value being much smaller than that of the diets used in the calorimeter experiments. The duration of the increment was also shorter, although it is evident that in many instances the basal value had not been reached at the end of the experimental period. The values given in such cases may be partial rather than maximum.

The large number of experiments with relatively pure carbohydrates permits a comparison of the values for the different kinds of carbohydrate. With dextrose it is seen that the cost of digestion ranges from 2 to 9 per cent, the average for 14 experiments with 11 subjects being 5 per cent. With levulose the total increments ranged from 3 to 9 per cent, and with one somewhat unreliable subject (J. J. C.) rose to 14 per cent. The average for 9 experiments with 8 subjects is thus approximately 7 per cent. With sucrose, the total increment varied from 3 to 9 per cent, with an average for 15 experiments with 9 subjects of 6 per cent. With lactose the total increment ranged from 3 to 6 per cent, with an average for 5 experiments with 5 subjects of 5 per cent.

If we compare the experiments on the basis of the amount of sugar ingested, we find that the average cost of digestion was practically the same for both 100 grams and 75 grams. The only exception was sucrose, which gave an average cost of digestion of 6 per cent for 8 experiments with 100 grams and of 5 per cent for 7 experiments with 75 grams, the average for all experiments being 6 per cent.

It is thus seen that the cost of digestion for the carbohydrates studied in these 43 respiration experiments does not differ materially in the proportion of increase, averaging not far from 6 per cent (5.5 per cent to be exact) of the fuel value of the intake. This figure, 5.5 per cent, is almost precisely the average obtained in 22 calorimeter experiments (5.6 per cent), although in those experiments mixed carbohydrates were taken, such as bananas, popcorn, and rice, rather than pure carbohydrates.

A relatively large number of respiration experiments were made with the protein-rich food, beefsteak, in which the fuel value[1] ranged from 234 to 532 calories, or 790 calories if we include the experiment with beefsteak and potato chips. A strict averaging of these experiments is not permissible, owing to the differences in the time relations. Large increments are noted in several instances with several values for the

[1]It should be noted that the beefsteak used in these experiments contained a certain proportion of fat, which supplied from 24 to 37 per cent of the fuel value. Consequently, the cost of digestion of the protein itself is not represented by the figures given. In all probability the true value would be higher.

cost of digestion of 16 per cent or more. The average cost of digestion for all of the beefsteak experiments is 13 per cent, more than twice the value observed with the carbohydrates. In the experiment with whole milk, a cost of digestion of 3 per cent was found, while the two experiments with a mixed diet gave values of 6 and 4 per cent, respectively, these being not far from the values obtained for the calorimeter experiments.

Emphasizing again the fact that in drawing conclusions from the results given in these two tables it should be remembered that the figures given are low rather than maximum values, since in the majority of instances the basal value was not reached before the conclusion of the experiment, we may conclude that the average cost of digestion for the ingestion of pure carbohydrates or a predominatingly carbohydrate meal will be not far from 6 per cent of the fuel value of the food ingested. With fat it is approximately 2 per cent and with a protein-rich diet it averages 12 per cent. With a mixed diet, which more properly corresponds to every-day usage, 6 per cent is doubtless near the correct value.

SPECIAL RELATIONS OF PROTEIN DIETS TO ENERGY TRANSFORMATIONS.

With diets consisting primarily of carbohydrates and fat no special indices are available as to the proportion of fat and carbohydrate burned in the body other than the relationship between the carbon-dioxide production and the oxygen consumption; but when protein enters into the katabolism, especially in excessive amounts, the nitrogen in the urine has commonly been taken as an index of the amount of protein katabolized. The intimate relationship between protein katabolism and heat production has been so pronounced as to lead writers to calculate quantitative relationships between heat production and the nitrogen excretion of the urine.

In the computation of the total energy transformation by means of the respiratory exchange, emphasis is laid for the most part upon the measurement of carbon-dioxide excretion and oxygen consumption, and heat production is computed from the calorific value of the carbon-dioxide or oxygen at the respiratory quotient actually measured. There are two methods for computing heat production from the calorific values for carbon dioxide and oxygen. In one no special attention is paid to the protein disintegration, on the general ground that usually about 15 per cent of the total energy is derived from protein metabolism. When a high degree of accuracy is desired, however, it is customary to compute from the respiratory exchange and the nitrogen in the urine the non-protein respiratory quotient, then compute the energy production due to the katabolism of the protein by multiplying the number of grams of nitrogen in the urine by a standard factor (26.51

calories). The remainder of the energy is then apportioned between fat and carbohydrate on the basis of the non-protein respiratory quotient. As previously stated (see page 203), this was not done in our computations of the energy from the gaseous exchange, as the non-protein quotient has relatively little significance, save in those experiments in which an excessive amount of protein was ingested.

By using the nitrogen excretion as an index of the protein katabolized, computing the total energy derived from protein and comparing it with the increment in the energy due to the ingestion of a protein food, certain relationships are made possible. This method of computation may be illustrated by using the results of the experiment with A. H. M. on April 5, 1907, in which 777 grams of beefsteak were taken by the subject. (See table 198, page 267.) The basal nitrogen excretion used was 1.06 grams per 2 hours (see table 28, page 80). The nitrogen excretion in the first 2-hour period following the ingestion of the food was 4 grams. The increment in the nitrogen excretion due to the ingestion of this large amount of a protein food was therefore 2.94 grams. As each gram of nitrogen in the urine represents a heat production from protein katabolized of 26.51 calories, the increment of 2.94 grams of nitrogen represents 78 calories of energy due to the increase in the amount of protein katabolized during this 2-hour period. Inasmuch as the total increment in heat production for the first period was but 31 calories, it is evident that at least 47 calories from the protein combustion took the place of energy originally derived from carbohydrate-fat combustion in a 2-hour period of the basal experiment. The total nitrogen excretion in the 8 hours of the experiment was 11.49 grams; the excess nitrogen excretion was therefore 7.25 grams, with an energy production of 192 calories due to the increase in the protein katabolized. The total increment in the heat production was but 136 calories; we may assume, therefore, that the replacement of basal energy derived from material other than protein was at least 56 calories.

The direct measurement of the protein disintegration from the nitrogen in the urine leads to the possibilities of further computation to determine the cause of the increase in the energy output following the ingestion of food. For example, when a protein food, such as beefsteak, is given in an experiment, we may compare the subsequent total increase in the metabolism (1) with the total energy of the food intake; (2) with the fuel value of the intake, thus obtaining the "cost of digestion"; (3) with that portion of the total energy or fuel value of the diet which is derived from protein alone; (4) with the total energy of the katabolized protein; or (5) with the increment in the heat production due to the increase in the amount of protein katabolized.

In the experiment with A. H. M. on April 5, 1907, the total effect of the ingestion of beefsteak was not obtained, as there was still a consider-

able increment in the metabolism even in the last period. We can not use the results, therefore, for an illustration of computing the specific dynamic action.[1] An experiment better adapted for this purpose is that with the same subject on May 24, 1907, in which the basal metabolism was obtained in the last period of the experiment and the total increment due to the ingestion of the beefsteak was therefore secured. (See table 200, page 269.) Following the usage of Rubner, the fuel value rather than the total energy of the diet may be used in the computation. The fuel value of the beefsteak eaten in this experiment was 644 calories, of which 70 per cent was derived from protein, or approximately 450 calories. The total increase in the heat production subsequent to the ingestion of the food was 70 calories. The total nitrogen excretion in the 8 hours of the experiment was 8.26 grams; as the basal nitrogen excretion which may be used for the same period is 4.24 grams, the excess nitrogen excretion due to the ingestion of the food was therefore 4.02 grams. This corresponds to an excess in the amount of protein katabolized (4.02 by 26.51) of approximately 107 calories as the result of an intake of 450 calories from protein.

A part of this increment of 70 calories may be properly ascribed to the influence of fat ingestion, since there was a considerable proportion of fat present in the beefsteak, but our evidence, as well as that of other investigators, indicates that the ingestion of fat has but a slight effect upon the metabolism and may probably be neglected in computations of this kind. Indeed, this was done in computing the values given in tables 249 and 250. The possibilities of differentiating between fat and protein in determining the influence upon the metabolism of the ingestion of a protein-fat diet should not, however, be lost sight of. It may be noted in this connection that Rubner carefully made such corrections in considering the influence of the protein-fat diets used in his experiments.

The experiments in our research with a predominatingly protein diet were not sufficiently extended or carried out with a sufficient degree of accuracy to justify a computation from their results of the so-called "specific dynamic action" of protein in the case of man. There is no question but that such a relationship exists between the increment in the protein katabolism and the increment in the heat production, but it may or may not be causal. Our experiments show that subsequent to the ingestion of a diet containing an excessive amount of protein there is prolonged and excessive heat production which continues for several hours. The nitrogen in the urine is likewise increased, although, as is seen from the foregoing discussion, the increase in heat production is

[1] Williams, Riche, and Lusk (Journ. Biol. Chem., 1912, **12,** p. 352) have pointed out in an interesting manner the methods of computing the specific dynamic action, so called, from an increase in the protein katabolism.

not sufficient to account for the total excess protein katabolized.[1] The fact should be recognized that this relationship is more apparent than real, for an increment in heat production is likewise found as the result of the ingestion of carbohydrates which is unaccompanied by material changes in the nitrogen excretion; one must therefore be cautious in associating too intimately the increase in the heat production with the increase in the amount of nitrogen excreted in the urine.

CAUSES OF INCREASE IN METABOLISM SUBSEQUENT TO INGESTION OF FOOD.

In the light of present knowledge, it would appear as a subject for severe criticism that an investigation on the influence of the ingestion of food upon metabolism which continued for a decade should show such relatively slight positive evidence contributing towards an explanation of the various phenomena observed. It was hoped that, as the research developed, definite information as to the cause or causes of the increase in the metabolism would be accumulated. Thus, in the earlier part of our research, impressed by the strength of the argument presented by Zuntz and his associates upon the influence of roughage or crude fiber in the diet, we included experiments with popcorn in our study on the influence of pure carbohydrates, on the supposition that the starch of the popcorn and the crude fiber of the hull would give roughage. As the research continued, however, it was found impossible to plan experiments, save under special conditions, for studying the cause of the increased heat production following the ingestion of food. Consequently our data represent for the most part only faithful records of a large number of experiments in which foodstuffs were given, either singly or combined, and the energy transformations subsequently measured. A careful search in our data for conclusive evidence as to the cause of this rise in the metabolism is, however, unsuccessful.

At the present time three explanations are offered of the increases noted with the ingestion of food. Zuntz and his associates, influenced largely by their extended experience with domestic animals, particularly with ruminants which consume considerable roughage and bulky food materials that remain for a long time in the intestine and require considerable digestive activity expressible in forms of muscular activity, maintained that the increase was due to the work of digestion, or *Verdauungsarbeit*. Rubner, as a result of his critical series of experiments on dogs, particularly the experiments with protein, was not inclined to attribute any share of the increase to the work of digestion,

[1]Attention should here be called to a recent study on the basal metabolism of dwarfs and legless men (Aub and E. F. Du Bois, Arch. Intern. Med., 1917, **19**, p. 864), in which the authors say that "following the ingestion of large quantities of meat, the excretion of urinary nitrogen during the earlier hours is not an accurate index of the protein metabolism. The sulphur excretion is more rapid than the nitrogen excretion."

but explained the increase upon the theory that each foodstuff exhibited a specific dynamic action, believing that the elaboration of food materials preparatory to absorption and oxidation, particularly the cleavage and elaboration of the protein molecule, accounted for the excess heat production. More recently the hypothesis of Friedrich Mueller[1] has been revived,[2] in that it has been maintained that the increase in the heat production is due to a stimulus to the cells as the result of products obtained from the food materials ingested or elaborated from them. That these products are in all probability of an acid nature is evidenced by experiments from this laboratory; the influence of amino-acids has been definitely proved by Lusk.[3]

Although practically none of our experiments were ideally planned to determine definitely the cause of this increase, certain phases of the work should be considered as an attempt to find if the phenomena agree with any of these explanations. Our experimental plan included, first, the establishment of a base-line, and second, a post-absorptive condition for the subject in each experiment, *i. e.*, that the subject should have been without food for at least 12 hours. It was assumed that comparison with such a base-line would give a true measure of the increase in metabolism due to food. The various factors affecting the basal metabolism have been considered in detail elsewhere[4] and likewise in our chapter on basal metabolism. (See page 47.) It is of interest to point out here, however, that even after the active digestion of food has ceased, Gigon concludes that there is considerable internal work which is characterized by Zuntz as *Verdauungsarbeit*. Indeed, Gigon ingeniously ascribes a depression found by him in the metabolism following the ingestion of 50 grams of olive oil as being due to the fact that the presence of the oil caused an abatement of the *Verdauungsarbeit* which had persisted during the experimental period. Furthermore, X-ray studies have definitely proved[5] that even during relatively prolonged fasting the motility of the stomach and the intestines does not entirely cease; this was likewise found by Boldireff.[6] In discussing the influence of the ingestion of food, it is especially necessary to bear in mind this activity of the digestive organs during the absence of food, including the movements of the alimentary tract, the secretion of the various digestive juices, and similar movements, for the ingestion of food may be supposed to increase the activity of all these factors.

[1]Mueller, Volkmann's Sammlung klin. Vorträge, May, 1900 (N. F. No. 272), p. 17.
[2]Benedict, Trans. 15th Int. Cong. Hygiene and Demography, 1913, **2** (2), p. 394.
[3]Lusk, Journ. Biol. Chem., 1915, **20**, p. 555.
[4]Benedict, Emmes, Roth, and Smith, Journ. Biol. Chem., 1914, **18**, p. 139; Benedict and Roth, Journ. Biol. Chem., 1915, **20**, p. 231; Benedict and Smith, Journ. Biol. Chem., 1915, **20**, p. 243; Benedict and Emmes, Journ. Biol. Chem., 1915, **20**, p. 253; Benedict, Journ. Biol. Chem., 1915, **20**, p. 263.
[5]Cannon, The mechanical factors of digestion, 1911.
[6]Boldireff, Arch. d. Sci. Biol., 1905, **11**, p. 1.

Any evidence bearing upon the possibility of intensive peristalsis or digestive action, or any series of experiments in which such stimulating agencies may be present, are of special interest in considering the cause for increased metabolism following food. Thus it is conceivable that the starchy foods would be more slowly acted upon than sugars, and yet an examination of the results of our experiments with such foods shows that they produced nearly as great an increment as the sugars did. (See tables 123, 124, 249, and 250, pages 196, 199, 336, and 338.) This is indeed surprising and might logically be taken as evidence in favor of the *Verdauungsarbeit* theory. While the dry starch of the popcorn could reasonably be considered as requiring a large amount of digestive work, it is hardly possible that bananas would contain material sufficiently irritating to the intestinal canal to have a great effect upon peristalsis or segmentation. At least two series of experiments carried out in this laboratory indicate that intestinal activity, as exemplified by the action of smooth muscle, does not measurably affect the metabolism. In one series the effect of purgatives and agar-agar was studied,[1] and in the second a study was made of the metabolism of dogs with ablated pancreas and consequently deficient digestibility.[2]

In view of the results obtained in these two series of experiments, we find it unconvincing to explain any portion of the increase subsequent to the ingestion of food as being due to *Verdauungsarbeit* in the sense in which Zuntz uses the term.

All writers who discuss the cause of the increase in heat production following the ingestion of food are at once confronted by the problem of giving a concrete explanation of the term "specific dynamic action," first used by Rubner. Perhaps no worker has considered this subject more in detail than Lusk, who has written one of the best expositions of Rubner's views that has ever been published.[3] Lusk proposes to compare the increase in heat production with the increased protein katabolized as a measure of the so-called "specific dynamic action," a process which is radically different from that originally employed by Rubner.[4]

Great difficulty is immediately experienced when we attempt to consider our experimental evidence in accordance with the prevailing views as to the cause of the increased heat production following food. Our experience with diabetics and with normal persons with a normally induced acidosis on a carbohydrate-free diet, as well as our experiments with unoxidizable material in the intestinal tract, lead us to favor more strongly the theory of acid-body stimuli, but it would be clearly a misuse of this present series of experiments to attempt to use them as experi-

[1]Benedict and Emmes, Am. Journ. Physiol., 1912, **30**, p. 197.
[2]Benedict and Pratt, Journ. Biol. Chem., 1913, **15**, p. 1.
[3]Lusk, Science of Nutrition, 3d ed., 1917, p. 232, *et seq.*
[4]Williams, Riche, and Lusk, Journ. Biol. Chem., 1912, **12**, p. 349.

mental evidence for any of the three current theories. It is of significance that popcorn and bananas, with their large content of fiber material, increase the metabolism, a fact which tends to support the *Verdauungsarbeit* theory. The well-known increases in peristalsis subsequent to the ingestion of pure sugars, especially levulose, would also probably be considered by the advocates of the *Verdauungsarbeit* theory as sufficient explanation of the increment noted with sugars. On the other hand, the results of the two studies previously referred to, in one of which excessive peristalsis was induced by the administration of Glauber salts and agar-agar to man, and in the other a study was made of the metabolism of dogs having defective assimilation due to ablated pancreas, strongly disprove the *Verdauungsarbeit* theory.

GENERAL CONCLUSIONS.

Many of the conceptions as to the influence of the ingestion of food upon the heat production have long been held and need no material modification. But as most of such evidence was obtained in experiments with animals rather than with men it seemed desirable for us to undertake a research upon the influence of the ingestion of food upon the metabolism of man. In making these experiments we have been greatly indebted to the earlier investigators, more especially to Magnus-Levy[1] and to Johansson and his school,[2] as their researches were in large part with men. It has been impracticable in our discussion to cite adequately the numerous observations made upon animals, particularly the classic experiments of Rubner and the more recent work of Lusk and his associates in New York. Believing that our problem was sufficiently extended if confined primarily to man, we have therefore intentionally omitted in this publication a review of practically all experiments made upon animals. In the decade or more that the results have been accumulating, numerous papers by other investigators have appeared, many of them reporting experiments with men. These we have considered carefully in our digest of the literature, as well as in the discussion of the several chapters.

The experimental evidence in this book as a result of our research presents little that is startlingly new. The mechanical work of chewing has been found to produce a definite increase in the metabolism. The drinking of liquids, especially in large amounts, likewise has been shown to increase the metabolism, although these increases are usually relatively small. The fact that the ingestion of all kinds of food in any amount results in an increment in the metabolism seems very clearly established. No conclusive evidence of a metabolism depressed below

[1] Magnus-Levy, Arch. f. d. ges. Physiol., 1894, **55**, p. 1.
[2] Johansson, Skand. Arch. f. Physiol., 1897, **7**, p. 29; same journal, 1902, **13**, p. 251; same journal, 1904, **16**, p. 263; same journal, 1908, **21**, p. 1.

the basal value after food has been found in any case. As our work was with man, it was obviously impracticable for us to use pure nutrients save in the case of sugars, and our experiments are thus open to this criticism. Hence, if we attempt to establish mathematical relationships for the effects of carbohydrates, fat, and protein, we at once meet the criticism that while the carbohydrates selected were, for the most part, pure nutrients, the fat and protein food materials were mixed nutrients, as, for instance, beefsteak, in which the protein was combined with fat, which also supplied a certain amount of energy.

Notwithstanding this defect in our experimental plan, the evidence obtained with diets in large part protein agrees with that secured by other observers with a protein diet, as an effect was found which was more pronounced and extended than that of any other nutrient. It appeared to make no difference whether the protein used was an animal or a vegetable protein, for the experiments with glidine on the one hand and with beefsteak and plasmon on the other are usually comparable.

Unfortunately the evidence obtained regarding fat is not so convincing, for our experiments are admittedly too few in number to give conclusive results and in the diets used the fat was combined with other substances; still the available energy derived from fat in the food intake was so large in most instances that the increment in the metabolism must necessarily have been due to this factor. Although the effect obtained was by no means so great as that found with protein, it can not be considered as negligible.

The most sharply defined results were those secured in the series of experiments with carbohydrate diets. It was possible to make a careful analysis of these data, compare the results obtained with the individual carbohydrates, and determine not only the total effect upon the metabolism measured, but likewise the time relations and the rapidity of the action of the food material. These results show in a striking manner that all of the carbohydrates influence the total metabolism and differ but little in this respect, although levulose and sucrose appear to exert a somewhat more powerful influence than the other sugars.

The experiments with mixed diets, especially those with excessive amounts of food, showed that it was possible by the ingestion of a large meal to stimulate the metabolism to 40 per cent above the basal value for a number of hours, and to 20 per cent for at least 8 hours; indeed, there was every reason to believe that the stimulus to the metabolism would have been found to continue considerably longer than the experimental period of 8 hours if the observations had been prolonged. This fact has a special practical significance in its relation to the daily life of human individuals. While it is possible for a human being to live with greatly reduced activity when sound asleep, without food in the stomach, and without extraneous muscular activity, his efficiency

as a member of human society in such a state would be negligible. It is therefore only as the cellular activity increases that we find him becoming more and more of service to humanity, and not until he is erect and ready to perform active external muscular work is he in a condition to live on a basal plane that is of practical value.

The ingestion of food with its attendant increase in metabolism appears at first thought like a highly inefficient process, this increase being comparable to the extra energy required by a donkey engine to stoke the boilers in a large factory; so far as the direct mechanical output of the factory is concerned, the energy thus used appears as waste, and yet it is necessary in order to secure a supply of fuel to the boilers. The increment in the metabolism or excess energy given off by the body as a result of the ingestion of food may be considered as the energy required for the preparation of material for use in the body tissues, and on this basis may be regarded as waste energy. Indeed, it is the belief of some writers that heat is invariably a waste product and that this factor has interest only in that it is developed in connection with muscular or glandular activity. Another phase of the situation appears, however, when we consider that the extra heat developed under these conditions may possibly be looked upon as a normal physiological stimulus to cellular activity. In this connection the practical experience of many investigators may be mentioned, especially those making observations with severe muscular work in studies with a protein diet and, in many cases, with a carbohydrate diet, such as sugar or sweet chocolate. If it be true that the increase in the metabolism resulting from the ingestion of such diets has a specific influence in stimulating the whole cellular system of the body to greater activity, then we may not properly regard this excess heat as a waste product.

Continuing the discussion in the terms of the efficiency engineer, it may be possible to consider the increase in heat production due to food as a measure of the "cost of digestion." For instance, the ingestion of 1,000 calories of food in the form of sugar requires the excess production of 60 calories of heat in order to have the sugar ready for an actual share in the muscular work. On this basis, one might compute that this excess heat was lost and that when 1,000 calories in the form of cane sugar are transformed into material ready for combustion in the body only 940 calories are available for such use. If, then, the increments in heat production obtained in our various experiments are computed and compared with the fuel value of the food ingested, the proportion of the energy in the ingested food which was given off as excess heat may be determined. One great difficulty in securing such data is the fact that in many instances the experiments did not continue long enough to include the entire heat increment. This is particularly true in the protein experiments, for frequently (see table 215, page 284) the basal value was not reached before the end of the experiment.

The data showing the relationship between the excess heat and the fuel value of the intake, which are given in tables 249 and 250 (see pages 336 and 338), vary considerably with the length of the experiment, the total amount of the food intake, and the nature of the diet. While, for lack of a better terminology, the values are designated as the "cost of digestion", the use of such a term is distinctly misleading, as implying that this excess heat is waste heat. We are firmly convinced that the excess heat produced from the ingestion of protein or carbohydrates, like sugars, may not properly be considered as purely a waste process, but that it is far more logical to consider it as a general stimulation of all of the cells in preparation for the drafts of muscular activity.

Our results give no basis for recommending an exclusively protein diet or an exclusively sugar diet prior to severe muscular work. That the presence of glycogen in the body has an important bearing on the efficiency of the muscular system is, in general, we think, proved without doubt. That any food substance that will contribute toward the replenishment of a depleted glycogen store or will maintain this at a high level is important in the preparation for muscular work, we likewise may consider as being thoroughly established. The formation of glycogen from sugar is unquestionably proved; the formation of glycogen or sugars from protein is likewise demonstrated; but there is as yet no evidence that sugar is formed from fat. It follows, therefore, that diets preceding muscular work should contain liberal quantities of carbohydrates or protein, although our evidence does not allow us to determine which is the more important, the furnishing of glycogen or the normal stimulus to the body. There is no question but that protein is a more prolonged stimulus to the metabolism than carbohydrate. On the other hand, in the digestion of protein extra work is thrown upon the organs of excretion. Too much significance may be given to this, but nevertheless, since the ingestion of carbohydrates does not require such work, there appears to be a legitimate ground for questioning whether an excessive protein diet or an excessive carbohydrate diet would be the more desirable to provide a glycogen storage as preparation for muscular work. The value of large diets of either protein, carbohydrate, or mixed nutrients to replenish the glycogen depots and stimulate the whole body to cellular activity is plainly shown by our experiments. The practical application of this fact would seem to lie more particularly in the preparation for those bodily activities calling for considerable muscular work.

APPENDIX.

SUGGESTIONS AS TO METHOD FOR STUDYING THE EFFECT UPON BASAL METABOLISM OF INGESTION OF FOOD OR DRUGS.

In reporting the results of these investigations on the effect of the ingestion of food upon the metabolism, it seems appropriate, in view of our experience with various foods and numerous subjects during the past 12 years, to offer suggestions as to the methods to be employed for an ideal study of this problem. These suggestions are based not only upon the actual work here reported, but also upon much experimenting carried on since most of this work was done.

Objects.—We must first recognize the objects of such a study. These are the determinations of (1) the total effect upon the metabolism of the ingestion of food, namely, the increase above the basal metabolism; (2) the highest increase above the basal metabolism and its time relation to the taking of food, *i. e.*, the peak effect; and (3) the subsequent character of the metabolism to note whether it remains unaltered or if there is a change in the proportions of protein, fat, and carbohydrate metabolized.

Subjects.—It is obvious that the subjects selected should be primarily normal, healthy individuals, without tendency to digestive disturbances. Only through a knowledge of the metabolism of normal individuals can we gain information as to the abnormalities in the metabolism after food ingestion under pathological conditions. Individuals who are likely to continue throughout an entire series of tests are to be preferred, as they may be depended upon for subsequent duplicate and control experiments. Repeated experiments with the same individuals obviate the necessity for training new subjects, lead to an improvement in the experimental routine, and reduce the number of subjects required for obtaining results which will supply definite conclusions. The training of pathological subjects is more difficult than the training of normal subjects; moreover, the physical condition of such subjects is liable to variation. A greater number of experiments is accordingly necessary for a series of investigations with pathological conditions.

Basal metabolism.—Since the object of any study of the metabolism subsequent to food ingestion is to determine the effect upon the basal metabolism, *i. e.*, the metabolism in the post-absorptive condition (12 hours or more after the last food ingestion), it is necessary first to obtain an accurate measure of the basal metabolism. As our own unfortunate experience only too frequently shows, it is imperative to determine the basal metabolism and the metabolism after food upon the same day, save perhaps in exceptionally prolonged experiments. When this is not done the basal metabolism determined on another day may be higher than the true basal metabolism of the food day, thus leading to the conclusion that the effect of the food is negative. Furthermore, there should be a preliminary period of observation which should be continued 30 minutes or preferably longer, so that one may state with certainty that the basal level has been reached before the actual measurements are begun. During this preliminary period the subject should be at rest and in the same body position as during the experimental period.

Control of external muscular activity.—It has been repeatedly stated in publications from this Laboratory[1] that, in any study of metabolism in which comparable results are to be obtained, it is necessary to have as nearly as possible complete muscular repose and that there must be a graphic record which will indicate that such repose has been maintained throughout the periods of the experiments which are compared with each other. Such a graphic record may be obtained either by means of pneumographs around the thighs and thorax or by means of a pneumograph or pneumatic bulb connected to the bed support. If these devices are connected with a sensitive recording tambour, the slightest muscular movement of the subject results in a change in the volume of the air in the pneumograph, which is immediately recorded by the pointer of the tambour upon the smoked surface of the rotating drum of a kymograph.

In addition to the record of the amount of complete external muscular repose it is equally important to note any drowsiness or sleep which may occur during the measurement of the metabolism. Recent experience with human subjects in a series of experiments upon the metabolic effect of the ingestion of alcohol has shown that the degree of wakefulness can be satisfactorily recorded by having the subject press a push button periodically in response to a stimulus. The stimulus is supplied by a signal magnet which is operated once every half minute. The magnet is so placed that the subject can hear it readily and is in series with a battery, clock, and second signal magnet which records upon a moving kymograph drum. The push button operated by the subject is connected with a battery and an independent recording signal magnet, thus giving a record of the response to the signal. A continuous record of responses gives positive evidence of wakefulness on the part of the subject, while a continuous lack of responses is indicative of drowsiness or actual sleep.

The effect of external muscular activity is to change the total metabolism, while the effect of drowsiness or sleep is to change the apparent character of the respiratory exchange; accordingly, a graphic record of both is essential for a reliable interpretation of the results obtained.

Length of periods.—The length of the periods of observation is naturally dependent upon the total effect to be measured and upon the apparatus used. When the effect is exceedingly small, and particularly when the peak effect and its time relation are desired, it is essential to make the periods as short as possible, preferably 10 to 15 minutes. If an apparatus with a closed chamber is used, periods as short as these are not possible; with such an apparatus, periods of at least 30 minutes should be employed and 45-minute periods are more reliable.

Apparatus.—From the experience of the last 12 years in studies of this character, we have come to the conclusion that some form of respiration apparatus is desirable with which it is possible to measure the gaseous exchange continuously in short periods. At present the best combination for this purpose with a trained subject is found to consist of a face mask, valves for separating inspired and expired air, two spirometers (preferably of the Tissot type), and a Haldane portable gas-analysis apparatus for analyzing the expired air. The face mask is one used in the Siebe-Gorman mine-rescue apparatus.[2] To secure reliable results, the tightness of the mask against the face must be assured. The valves for separating inspired and expired air most used in this laboratory are the Thiry-Tissot model,[3] but any valve which is

[1]Benedict, Deutsch. Arch. f. klin. Med., 1912, **107**, p. 156; Benedict and Talbot, Carnegie Inst. Wash. Pub. No. 201, 1914, pp. 31 and 59; Benedict, Carnegie Inst. Wash. Pub. No. 203, 1915, p. 311.

[2]This may be obtained from H. N. Elmer, 1140 Monadnock Building, Chicago, Ill.

[3]Both the Thiry-Tissot valves and Tissot spirometer were obtained from Pirard and Coeurdevache, 7 rue Blainville, Paris, France.

lightly movable and gives perfect closure without backlash is suitable. The spirometers are of the Tissot model. A complete description of this spirometer is given in a former publication from this Laboratory.[1] Any spirometer which is lightly movable and fairly well counterpoised is practicable for this purpose. The 100-liter spirometer is the most adaptable for general use. The portable gas-analysis apparatus is the one devised by Haldane[2] for the analysis of atmospheric, mine, and expired air. Its accuracy should be controlled by analyses of atmospheric air. The apparatus, when properly set up, should give 0.03 per cent CO_2 and 20.93 to 20.95 per cent O_2 for atmospheric air. We insist on this as a proof of the accuracy of the analysis of the expired air. Such analyses should be reported in connection with the results of metabolism measurements.

With the combination of apparatus outlined in the foregoing paragraphs, a trained subject awake, and a complete absence of external muscular activity, it is possible to measure the peak effect of either the metabolism or of the respiratory quotient, or to measure the effects of the ingestion of exceedingly small amounts of material. During the past two years the gaseous exchange and respiratory quotients of trained subjects have been measured for 6 to 7 hours in consecutive experimental periods as short as 10 minutes, with no great degree of discomfort to the subject and with a high degree of accuracy.

When the increments in metabolism are likely to be large and to extend over a considerable period of time, and when it is possible to repeat the experiment several times, the clinical respiration apparatus (a chamber apparatus)[3] is probably the most feasible. In this apparatus it is not necessary for the subject to remain absolutely immovable and the possibility of movement makes it pleasanter for the subject in long experiments.

Summary.—From the foregoing it can be seen that the ideal method for determining the effect of the ingestion of food upon the metabolism is the use of trained subjects; a measurement of the basal metabolism on the same day as that following the ingestion of food; an absolute absence of external muscular activity; a subject awake; graphic records of both the absence of activity and any evidence of drowsiness or sleep; as short periods as possible; spirometers, respiratory valves, face mask, and portable Haldane gas-analysis apparatus, with determinations controlled by analyses of atmospheric air.

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[1]Carpenter, Carnegie Inst. Wash. Pub. No. 216, 1915, p. 61.
[2]Haldane, Methods of air analysis, 1912, p. 47.
[3]Benedict and Tompkins, Boston Med. and Surg. Journ., 1916, **174**, pp. 857, 898, and 939.

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